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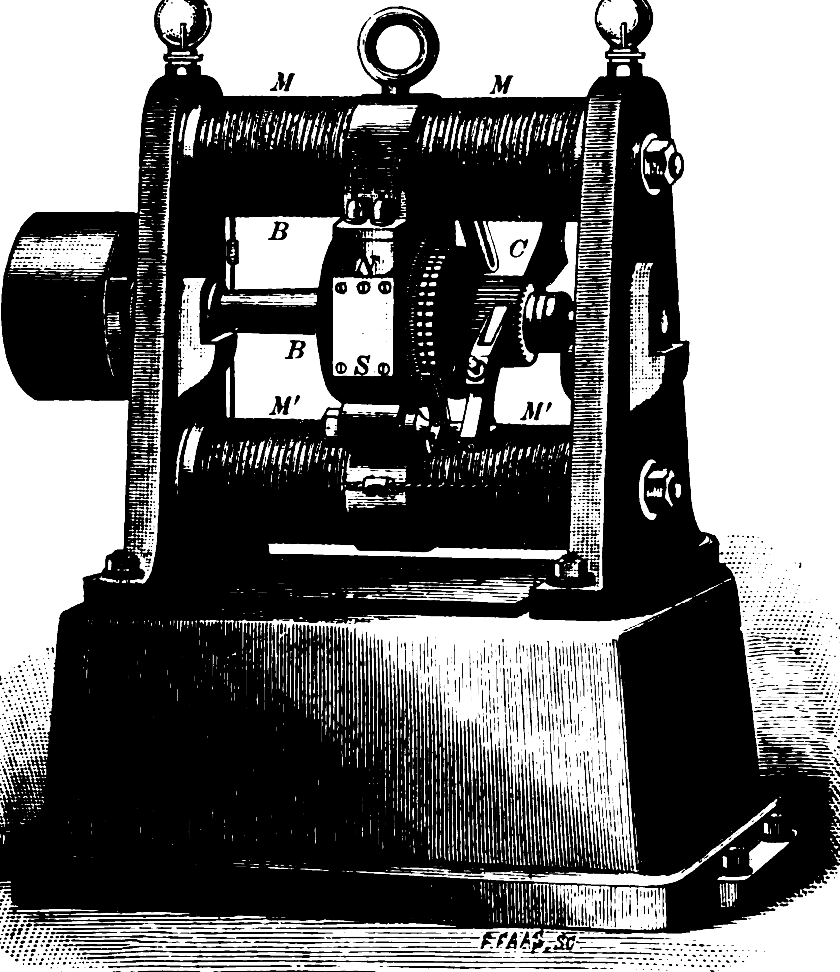

Intermediate lessons in natural philosophy

Edwin James Houston

INTERMEDIATE LESSONS

IN

NATURAL PHILOSOPHY.

BY

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ELEMENTS OF PHYSICAL GEOGRAPHY. ETC., ETC.

PHILADELPHIA:
ELDREDGE & BROTHER,
No. 17 North Seventh Street.
1881.

A SERIES OF TEXT-BOOKS
ON
THE NATURAL SCIENCES.

By Prof. E. J. HOUSTON.

1. **Easy Lessons in Natural Philosophy.**
2. **Intermediate Lessons in Natural Philosophy.**
3. **Elements of Natural Philosophy.**
4. **Elements of Physical Geography.**

J. FAGAN & SON,
ELECTROTYPERS, PHILAD'A.

KEYSTONE PRESS OF Wm. J. DORNAN PHILADELPHIA

PREFACE

THIS book has been prepared at the request of numerous teachers. As its name indicates, it is an intermediate work, and is intended to fill the gap between the author's "Easy Lessons in Natural Philosophy" and his "Elements of Natural Philosophy." In extent and scope it has been so graded as to enable it, in connection with the two other works, to form a comprehensive series, suited to the wants of high schools and academies. Each of the lower books of the series, though complete in itself, leads naturally to the next higher.

The text, as far as practicable, is based on experiments. These experiments are of an exceedingly simple character, and can readily be performed without the aid of an expensive cabinet of apparatus. Plain and simple instructions are given as to the proper manner of performing the experiments, and the attention of the student is especially called to the particular points to be observed during the progress of each experiment. The facts so developed are afterwards fully discussed in the text.

The author trusts that the book will be found to meet the requirements of actual school-room work.

E. J. H.

Central High School,
Philadelphia, January, 1881.

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INTERMEDIATE LESSONS
IN
NATURAL PHILOSOPHY.

CHAPTER I.

MATTER.

1. Matter.

Experiment (1).— Fill a goblet to the brim with water. Drop a stone gently into the water. Observe that some water will run out of the goblet.

When the stone falls through the water, it pushes some of the water out of its way, and thus clears a space for itself, which it then fills. To do this, the stone must cause as much water to run out of the goblet as will fill a space just as large as the stone.

The stone pushes the water out of the way, because it and the water cannot be in the same place at the same time. It is the same with a body moving through the air; it cannot move until it pushes the air out of the way.

When a nail is driven into a board, it must first push portions of the board out of the way before it can enter the board, because both the nail and the board occupy or fill space, and cannot be in the same space at the same time.

The stone, the water, the air, the board, and the nail are formed of what is called matter.

Matter is anything which occupies space and keeps other things from occupying the same space.

Nearly everything around us is made of matter; thus, the trees, houses, stones, books, chairs, and tables are made of matter, since they fill space and prevent other things from filling the same space at the same time.

Experiment (2).— Place the goblet in the sunlight, while filled to the brim with water. The sunlight will then also fill the goblet. Observe that none of the water runs out.

Experiment (3).— Hold a book so that its shadow falls on the goblet. Observe that the goblet is as full of water as before.

The sunlight, or the shadow of the book, can then be in the same place that the water is; they are not therefore kinds of matter.

2. The Senses.— We become aware of the presence of matter by means of our senses. We see, feel, taste, or smell matter. Moreover, we can learn to distinguish between different kinds of matter by the difference in our sensations; thus, all things do not look alike, their color differs; they do not feel the same when we touch them; some are smooth, others are rough; some feel hard, others soft; they differ also in their taste and smell.

3. Substances.— Different kinds of matter are called substances. Iron, brass, coal, water, milk, steam, and air are substances.

All substances are either elementary or compound.

An element or elementary substance is one that has never been separated into more than one kind of matter.

Iron is an elementary substance. We cannot by any known means separate or break it up into anything but iron.

A compound substance is one formed by the union of two or more elementary substances.

Brass is a compound substance. It can be separated into copper and zinc; or by melting copper and zinc together we can produce brass.

Most substances are compound. All the compound substances in the world are formed by the various combinations of about seventy elementary substances.

In some compound substances there are only two different elements; in others, there are three, four, or more.

A body is the name given to any piece of matter. Bodies may be large or small; thus, our earth, and a grain of sand, are both bodies.

4. Properties of Matter.— All substances have different peculiarities or properties which enable us to recognize them. We can distinguish gold from marble, because their color and weight are different; then, too, gold can be beaten out into thin sheets, while marble cannot.

5. Changes of Matter.— Matter is constantly undergoing changes; these changes are of two kinds, viz., *physical* and *chemical.*

Experiment (4).— Take a hard rubber comb, or rubber button and rub it briskly against the coat. Observe that its appearance is the same after rubbing as it was before. The rubbing, however, has caused a change in the thing rubbed, and given it properties it did not have before; if held near small shreds of cotton, or pieces of paper, it will cause them to move, first towards it, and afterwards away from it.

Experiment (5).— Take a steel pen and rub it once or twice against the end of a steel magnet. Observe that the pen has the same appearance that it had before being rubbed. The rubbing, however, has caused a change by which the pen has acquired properties it did not have before. It will now attract or draw iron filings to it.

Those changes that can take place in a substance without depriving it of the properties it generally possesses, are called *physical changes.*

The changes in the hard rubber, and in the pen, are physical changes, since they occur without taking away from these bodies the properties they generally possess.

Experiment (6).— Expose the pen for a few days to damp air. Observe that it has become covered with a thick brown rust, formed by oxygen, a substance in the air, combining with the iron of the pen.

Those changes that cannot take place in a substance without depriving it of the properties it generally possesses, are called *chemical changes.*

The part of the pen converted into rust has undergone a chemical change; for the rust does not possess the properties of either of the substances out of which it was formed, since one of them, the oxygen, is an invisible gas, and the other is the pen itself.

6. Cause and Effect. Phenomena.—Nothing happens without a cause. When a bell is struck, it sounds; soon, however, it ceases to sound, and will remain silent until it is again struck. Here the blow is the cause which has made the bell sound; the sound is the effect.

Unsupported bodies fall to the earth. Here we cannot see the cause, namely, the attraction of the earth; we only see the effect, namely, the fall of the body.

A phenomenon is anything that occurs in the ordinary course of nature. The sound of a bell, and the fall of a body to the earth, are phenomena.

7. Natural Law.—The same cause acting in the same way always produces the same effect. A bell when properly struck will always sound. Unsupported bodies always fall to the earth.

When we have discovered the relation that exists between cause and effect and expressed it in words, we have what is called a natural law.

8. Observation and Experiment.—There is but one way to discover natural laws; that is, to *experiment, and then carefully observe what happens.*

9. Natural Philosophy and Chemistry.—*Natural Philosophy* is the study which considers the causes and effects of the physical changes that occur in matter.

Chemistry is the study which considers the causes and effects of the chemical changes that occur in matter.

10. Force and Energy.—All natural phenomena are caused by the action of certain forces.

A pound weight may be raised by the muscular force of the arm through a distance of one foot; if the force continue to act, the weight may be raised through two feet. Here, in both cases, the force causing the motion is the same, namely, the muscular force of the arm; but the *energy, or the amount of work done*, is twice as great in the latter case as in the former.

By *energy*, we mean the amount of work that can be accomplished by the action of any force.

11. Both Matter and Energy Indestructible.—As far as we know, there exists a certain definite quantity of matter and energy in the universe. By no possible means can we increase or decrease either the quantity of matter, or the quantity of energy. During changes, one or both may disappear, but only to reappear in some other form.

Experiment (7).—Burn a piece of paper or wood. Observe that it nearly all disappears. It has not, however, been blotted out of existence, but by the act of burning has been changed into invisible gases; while the heat which accompanies the burning, has acted on the matter around it and caused changes therein.

SYLLABUS.

Matter is that which occupies space and keeps other things from occupying the same space.

A stone dropped into water cannot move through the water until it has pushed some of the water out of its way; for, since both the water and the stone are matter, they cannot both be in the same place at the same time.

A vessel filled with water can be placed where it will also be filled with sunlight, without any of the water running out. Therefore, sunlight is not a kind of matter.

We can see, feel, touch, or taste matter.

Different kinds of matter are called substances. Substances are either elementary or compound.

An elementary substance is one that has never been separated into more than one kind of matter; as iron.

A compound substance is one formed by the union of two or more elementary substances; as brass.

By the properties of a substance we mean those peculiarities by which we recognize that substance.

The changes that occur in matter are either physical or chemical. By a physical change, a substance does not lose its common properties; by a chemical change, it loses these properties.

A phenomenon is anything that occurs in the ordinary course of nature. All phenomena are effects produced by certain natural causes.

A natural law expresses the relation that exists between the cause and effect of phenomena.

By energy, we mean the amount of work that can be accomplished by the action of any force.

Both matter and energy are indestructible.

QUESTIONS FOR REVIEW.

A stone whose volume is equal to three hundred and twelve cubic inches is dropped quietly into a vessel filled with water. How much water will it cause to run out of the vessel? Why?

How can you tell whether anything is made of matter or not?

In what different ways may we become aware of the existence of matter?

Name some different kinds of substances. What is meant by an element or elementary substance? By a compound substance? Give examples of each.

What is meant by a physical change? By a chemical change? Give examples of each.

Define cause; effect; phenomenon. Give examples.

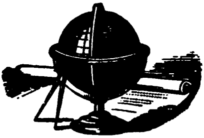
What is meant by a natural law?

Define Natural Philosophy. Define Chemistry.

By what are all natural phenomena caused?

What is meant by energy?

Can either matter or energy be destroyed?



CHAPTER II.

PROPERTIES OF MATTER.

12. General Properties of Matter.— There are certain peculiarities or properties possessed by all kinds of matter. These are called the *general properties* of matter.

Some of the more important of the general properties of matter are *magnitude or extension*, *impenetrability*, *porosity*, *compressibility*, *expansibility*, *mobility*, *and inertia.*

13. Magnitude or Extension.— All matter fills space or occupies room. This property is called magnitude or extension. Matter extends or fills space in three directions; viz., in length, in breadth, and in thickness.

In this country we measure the dimensions of a body in inches, feet, yards, or miles. In France and Europe generally, dimensions are measured in metres or parts of a metre.

ENGLISH MEASURE.

Measures of Length.	*Measures of Surface.*	*Measures of Volume.*
12 in. make one ft.	144 sq. in.=1 sq. ft.	1728 cub. in.=1 cub. ft.
3 ft. " " yd.	9 sq. ft.=1 sq. yd.	27 cub. ft.=1 cub. yd.
1760 yds., or 5280 ft., make one mile.		

FRENCH MEASURE.

Measures of Length.

1 metre	equals	39.37	English in., or 3.280 ft.	
1 decametre, or 10 metres	"	393.7	"	
1 hectometre, " 100 "	"	3937.	"	
1 kilometre, " 1000 "	"	39370.	"	" 1093.6 yds.
1 decimetre, " $\frac{1}{10}$ of a metre	"	3.937	"	
1 centimetre, " $\frac{1}{100}$ " "	"	.3937	"	
1 millimetre, " $\frac{1}{1000}$ " "	"	.03937	"	" $\frac{1}{25}$ in. nearly.

Measures of Area or Surface.

1 square metre	equals	1550.06	sq. ins., or 10.764 sq. ft.	
1 " decimetre	"	15.5006	"	
1 " centimetre	"	.155006	"	
1 " millimetre	"	.00155006	"	

Measures of Volume.

1 cubic metre	equals	61027.1	cub. in., or 35.3166 cub. ft.	
1 " decimeter, or litre	"	61.0271	"	" .2202 gals.
1 " centimetre	"	.061027	"	

The measures of surface are found by squaring the measures of length. Thus, 12 inches × 12 = 144 square inches, or one square foot. 3 ft. × 3 = 9 square feet, or one square yard. 39.37 ins. × 39.37 = 1550.06 square inches, or one square metre.

The measures of volume are obtained by cubing the measures of length. Thus, 12 ins. × 12 × 12 = 1728 cubic inches, or one cubic foot.

The following table will be of use in changing English into French measures.

1 inch = 25.40 millimetres.
1 foot = .3048 metre.
1 yard = .9144 metre.
1 mile = 1.609 kilometres.

The value of one square inch can be obtained by squaring 25.40 millimetres = 645.16 sq. millimetres. The value of one cubic inch can be obtained by cubing 25.40 = 16387.06 cubic millimetres.

Fig. 1 represents the actual length of a French decimetre; and Fig. 2 the actual length of four English inches. Since a decimetre equals 3.937 inches, it is but a trifle shorter than four English inches. From *A* to *B* is one decimetre; from *A* to *a* is one centimetre, of which there are ten in one decimetre, or in the whole length of *A B*. From *A* to *b* is one millimetre, of which there are ten in every centimetre.

From *C* to *D* is four English inches; from *C* to *a* is one inch; from *C* to *b* is one-tenth of an inch. There are about twenty-five millimetres in one inch.

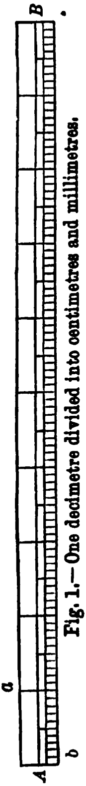


Fig. 1.—One decimetre divided into centimetres and millimetres.

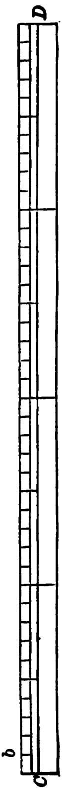


Fig. 2.—Four inches divided into tenths.

PROBLEMS.

(**1.**) How many metres are there in one English mile? (**2.**) How many millimetres are there in one foot? (**3.**) In 5468 yards, how many kilometres are there? (**4.**) Reduce 25,400 millimetres to feet. (**5.**) Find the number of square metres in one square yard. (**6.**) How many English miles are equal to 225.26 kilometres? (**7.**) In one cubic mile how many cubic kilometres are there? (**8.**) How many millimetres are there in one foot? (**9.**) How many gals. are there in one cubic metre? (**10.**) How many cubic decimetres are there in 100 gallons?

14. Impenetrability.—We have seen in Chapter I. that two different bodies cannot occupy the same place at the same time. This property is called impenetrability.

Experiment (8).—Hold an empty glass goblet mouth downwards in a vessel of water. Observe that the water does not rise and fill the goblet. It does not rise because the goblet is already full of air, and the water and the air cannot both occupy the same space.

15. Divisibility.

Experiment (9).—Pour a few drops of red ink or crimson writing fluid into a large goblet or pitcher of clear water, and thoroughly mix. Observe that all the water is colored.

Since a few drops of the red substance have colored the many thousand drops of water, there must be some of the red coloring matter in each of the drops of water. The quantity in each drop of colored water must therefore be very small.

Divisibility is that property of matter in virtue of which a substance can be divided or separated into smaller pieces.

There is no kind of matter so hard that it cannot be cut or ground into small pieces. These pieces may be made exceedingly small.

16. Illustrations.—Gold can be beaten into leaves so thin that about 300,000 such leaves piled together like the leaves of a book, would only make the pile one inch high, and yet each of these leaves can be cut into very small pieces.

A single grain of musk will give off its odorous particles to the air of a room for years without decreasing sensibly in weight. How very small, therefore, must these particles be!

By means of the microscope, we can see little animals so small that millions can easily swim about, in the space of a single cubic inch, without incommoding one another.

17. Atoms and Molecules.—Although, from the illustrations just given, matter seems to be divisible without limit, yet we believe that there is a limit beyond which it would be impossible to further divide it. The smallest particles into which it is possible to divide matter are called *atoms*. The word atom means that which cannot be cut.

The atoms are exceedingly small: they seldom exist separately, but combine with one another and form groups called *molecules*. Molecules, though larger than atoms, are nevertheless much smaller than the smallest particles into which we have been able to divide bodies.

The smallest quantity of a compound substance that can exist, is a molecule of that substance. Water is a substance formed by the combination of two atoms of hydrogen with one atom of oxygen. Any compound containing less than two atoms of hydrogen and one of oxygen would not be water. Therefore, the smallest particle into which it would be possible to divide water would be its molecule.

It will be observed that the atom is the smallest possible particle that can exist. The molecule is also very small, but of course larger than the atom, since it is composed of several atoms. By the word molecule is meant, in general, a very small particle of matter.*

18. Porosity.—All matter is composed of atoms. Neither the atoms nor the molecules touch one another. Though they are much nearer together in some substances than in others, yet in no kind of matter are they believed to touch. The spaces between the atoms and molecules are called *pores*. All matter is *porous;* that is, has pores. The size of these pores varies: in some kinds of matter the pores can be seen, as in sponges and wood; in others we cannot see the pores, even with a microscope.

Even metals like gold are porous. Water may be forced through the walls of a strong vessel of gold without breaking the vessel. It must therefore be forced through the pores.

19. Compressibility and Expansibility.

Experiment (10).—Plunge an empty tumbler mouth downwards into a vessel of water. Observe that although the water does not rise as high inside the tumbler as on the outside, yet it rises higher on the inside, the further the tumbler is pressed down in the water. As the tumbler is pressed down in the water, the air in the tumbler is compressed into a smaller space, that is, its molecules are packed nearer together. Now raise the tumbler, still keeping its mouth under water. Observe that the air expands and fills the tumbler as before.

All matter when subjected to a pressure is compressed or made to occupy a smaller space. When

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* The word molecule will be frequently used in the different pages of this book. The teacher is therefore earnestly requested to be sure that the students have clear ideas as to its meaning.

this pressure is removed, many substances resume their original bulk.

Cold has the same effect on matter that pressure has; that is, matter when cooled *contracts* or decreases in bulk. When heated, matter expands or increases in bulk.

Experiment (11).—Hold an empty jar of thin glass (*A*, Fig. 3,) mouth downwards in a vessel of water so that the mouth of the jar is just covered by the water. Cover with the hand as much of the top of the jar as possible. Observe that, as the heat of the hand heats the air in the jar and causes it to expand, bubbles of air will escape from the mouth of the jar.

20. Mobility.— All matter can be moved or caused to change its place; that is, all matter possesses *mobility.*

Fig. 3.—Expansion of Air.

SYLLABUS.

The following properties are possessed by all kinds of matter; viz., magnitude or extension, impenetrability, porosity, compressibility, expansibility, mobility, and inertia.

Matter extends or fills space in three directions; viz., in length, in breadth, and in thickness; that is, all matter has volume.

Matter is impenetrable. No two bodies can occupy the same place at the same time.

All matter is divisible. Even the hardest substances known can be cut or divided into very small pieces.

The smallest particle of an elementary body that can possibly exist is called an atom.

The smallest particle of a compound body that can possibly exist is called a molecule. Even in elementary substances the atoms are combined in groups called molecules. The molecules, therefore, are larger than the atoms.

Neither the atoms nor the molecules touch one another in even the hardest substances, but are separated by spaces called pores: all matter is therefore porous.

By pressure, the molecules are packed more closely together, the pores become smaller, and the substance is compressed. By loss of heat, the molecules also come nearer together, and the substance contracts.

When matter is heated, the molecules are separated further from one another, the pores become larger, and the substance expands.

Therefore, when bodies expand or contract, it is not the size of their molecules that varies, but the size of their pores. It is the atoms and molecules that are impenetrable, not the spaces between them.

QUESTIONS FOR REVIEW.

Name the general properties of matter. Why are these properties called general?

Describe the English and the French measures of length, surface, and volume.

Give some examples of the great divisibility of matter. Define an atom. Define a molecule.

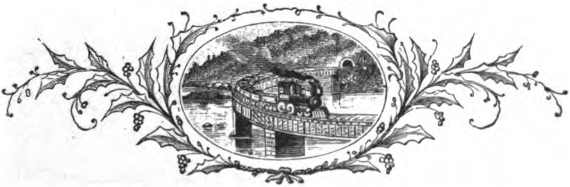
What name is given to the smallest particle of a compound substance that can exist? Give an example.

Define porosity. Is it the atoms and molecules, or the spaces between them, that are impenetrable? Is gold porous? How can this be proved?

In what two ways may the spaces between the molecules of a substance be increased?

What is the difference between compression and contraction?

Describe an experiment illustrating the expansibility of air. How may the compressibility of air be shown?



CHAPTER III.

INERTIA.

21. Inertia.—If a book, or other object without life, be placed on a table, it will remain at rest on the table until it is moved from it. Being dead, and having no force in it, the book must remain at rest until it is moved by something or somebody.

If motion be given to the book; if, for example, it be thrown up into the air, the book cannot stop moving until it loses all the motion given to it; for, being dead, it has no more power to stop moving than it has to begin to move, and, were it not for the resistance of the air and the attraction of the earth, it would continue moving upwards forever.

Our earth is moving through nearly empty space around the sun. Since there is nothing in this space to stop the earth's motion, and since the earth cannot stop itself, it must continue moving around the sun forever.

By the *inertia* of matter is meant the tendency that all matter has to continue in whatever condition of rest or motion it may be in until some force act on it.

That is, a body at rest will continue at rest forever unless some force act upon it; and a body in motion will continue moving forever unless some force act on it.

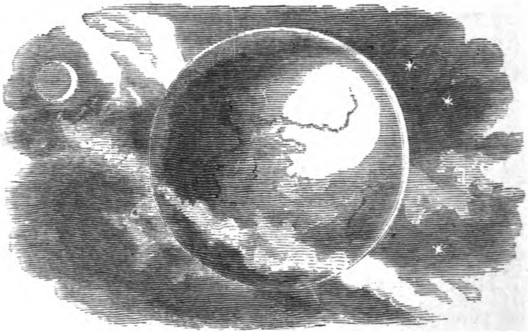


Fig. 4.—The Earth in Space.

22. Illustrations of Inertia.—A heavily-loaded wagon requires more force to start it moving than it does to keep it moving.

When a train of cars is started, it takes some time to get its full speed, because the inertia of the train has first to be overcome. When, however, it has reached its full speed, considerable force or energy must be exerted to stop it; for, when any body is moving, before it can be stopped it must lose all the energy that has been given to it in order to cause its motion.

Cannon-balls are so destructive because the explosion of the gunpowder has imparted considerable energy of motion to them.

Experiment (12).—Stand a large, heavy book upright on a sheet of paper. Pull the paper slowly towards you. Observe that the book does not fall, because, by the slow motion of the paper, time has been given to the whole book to acquire the motion.

Experiment (13).—While the book is moving, suddenly stop pulling the paper. Observe that the book falls towards you, because the top keeps on moving after the part resting on the paper has stopped.

Experiment (14).—Set the book again in an upright position, and pull the paper quickly towards you. Observe that the book falls backwards, because the lower parts of the book are moved forwards before the upper parts begin to move.

A person jumping from a rapidly-moving coach or car is apt to fall over, because, on touching the ground, his feet stop moving, while the rest of his body continuing to move, overthrows him.

When a car in rapid motion is suddenly stopped, the passengers in the car are thrown forwards.

Experiment (15).—Place a glass full of water on a table and suddenly push it forwards. Observe that the water is spilled or left behind, since the glass moves forwards before the water.

Experiment (16).—Take a glass of water in the hand: walk rapidly across the room and then suddenly stop. Observe that the water is thrown or spilled forwards, since it keeps moving after the glass has stopped.

23. Living Bodies Possess Inertia.—Before we can move about from place to place, we must exert our strength. As long as we continue to walk we must exert our strength. After we are once in motion, we must exert our strength before we can stop moving. If we are moving very fast, we must exert considerable strength in order to stop suddenly.

By "doubling," that is, by suddenly changing the direction of its motion, a flying hare escapes from a pursuing greyhound, because the dog, running at his greatest speed, cannot stop and turn quickly enough to follow the hare.

24. Resistances to Motion. — A body moving through air or water is resisted in its motion by the air or water, because it can only advance by pushing some of the air or water out of its way; and, since both air and water have inertia, they cannot move themselves out of the way, and therefore require that some force act on them before they can move. This force they take from the moving body, and thus diminish its motion. Resistances of this kind are called *fluid resistances.*

Another resistance to motion is caused by what is called *friction.* By friction we mean the resistance that bodies meet on being slid or rolled over one another. Friction is caused mainly by the irregularities that exist in even the smoothest surfaces; for, when one body is slid or rolled over the surface of another, the elevations of one surface, fitting into the depressions of the other, cause a resistance to motion.

There is but little friction between hard, smooth surfaces.

25. Illustrations of Friction.—A sled moves more easily over smooth ice than over the bare ground, because the friction of the sled on the ice is less than the friction of the sled on the ground.

Ashes sprinkled on icy pavements prevent us from slipping, because of the great friction they offer to our shoes.

There is but little friction between skates or sleds and smooth ice or snow; therefore the skates or sleds move easily.

In machinery, the parts that roll or slide over one another are greased or oiled, so as to diminish the friction, and prevent wear.

* * *

SYLLABUS.

A body at rest never begins to move, or, if in motion, never stops moving, unless some force acts on it.

When a body is thrown upwards through the air, it soon ceases to move upwards, because the resistance of the air and the attraction of the earth pull it down.

Our earth moves through the nearly empty space around the sun, where there is nothing to stop its motion. It must, therefore, continue moving forever.

By the inertia of a body we mean its tendency to continue in whatever condition of rest or motion it may have until some force acts upon it.

Before a body at rest can begin to move, some force must act upon it.

Before a body in motion can come to rest, it must give to bodies around it all the force or energy required to set it in motion.

Living matter possesses inertia. We must exert our strength either to begin to move, or to stop moving.

Air and water offer a resistance to the movement of bodies through them, because the moving body has to move the air or the water out of its way, and so loses part of its motion.

By friction we mean the resistance that is felt when we slide or roll two bodies over one another.

* * *

QUESTIONS FOR REVIEW.

What do you understand by the inertia of a body?

Why must our earth continue moving around the sun forever?

Why does a heavily-loaded wagon require more force to start it moving than it does to keep it moving?

Why do cannon-balls cause so much destruction to things in their path?

Describe any experiments illustrating the inertia of matter.

Why is a person jumping from a moving car apt to be thrown down?

What effect is produced on a passenger in a moving car by the sudden stopping of the car?

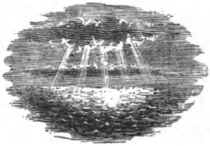
How does "doubling" aid a hare in escaping from a dog that is pursuing it?

Why does air or water retard the motion of bodies moving through them? Define fluid resistances.

What is the cause of friction? How may friction be lessened?

Why does a sled move more easily over smooth ice than over the bare ground?

Why will ashes sprinkled over icy pavements keep people from slipping?



CHAPTER IV.

THE THREE CONDITIONS OF MATTER.

26. Solids, Liquids, and Gases.

Experiment (17).—Place a lump of ice in a tin cup on the fire. Observe that the ice melts.

Experiment (18).—Allow the water to remain on the fire until it boils. Observe that the water gradually disappears and becomes invisible as it passes into the air. In this invisible state it is called a vapor or gas.

These experiments show that water can exist in three conditions or states; viz., in the solid state as ice; in the liquid state as water; and in the gaseous state as vapor.

Many substances can be made to assume all these conditions. Thus, iron when highly heated, fuses or melts; when heated still higher, it is changed into a vapor.

What happens to the ice when it fuses or melts, or to the water when it becomes changed into vapor? The molecules of the ice are of the same size as the molecules of water, or those of vapor. In the ice, however, the molecules are nearer together than in the water, and in the vapor they are further apart than in the water. The heat causes the ice to expand, and its molecules to get further and further apart, until at last, when they are a certain distance apart, the solid changes into a liquid. When heated, the water expands, and as it grows hotter, its molecules get further and further apart, until at last, when they are a certain distance apart, the water changes into a vapor.

The molecules, therefore, are nearest together in solids, and furthest apart in gases or vapors.

27. The Molecular Forces.— An unsupported body falls to the ground, because the earth attracts or draws the body towards it. The molecules also exert an attraction for one another, which causes them to be more or less drawn together. The stronger this attraction, the nearer the molecules are drawn to one another. The force which attracts or draws the molecules together is called the force of *molecular attraction.*

Besides the force of molecular attraction, there is the force of heat, which, as we have seen, tends to drive or push the molecules further and further apart. Heat, when acting in this way on the molecules, is sometimes called the force of *molecular repulsion.*

28. Solid Substances are those in which the molecules are attracted or drawn together with greater force than they are repelled or pushed apart.

In solids, the molecules are held so firmly together that they often require considerable force to separate them.

The force holding the molecules together varies in different solids.

Experiment (19).— Obtain a piece of tin and a piece of pasteboard of about the same thickness. Observe that the paper is easily cut or torn, and that the tin is cut or torn only with difficulty.

When we cut the paper or the tin, we simply separate its molecules; the molecules of the paper, therefore, must be held together with much less force than the molecules of the tin.

29. Illustrations.—A steel wire, so thin as to be invisible at a short distance, is strong enough to bear a man's weight.

In soft butter or wax, the molecules are held together with so little force, that these substances will scarcely retain the shape given to them.

30. Fluid Substances.— When the force of molecular attraction does not hold the molecules of any substance strongly enough together, to prevent them from easily moving or slipping over one another, the substance is called a fluid, because it can flow readily.

There are two kinds of fluid substances; viz., *liquids* and *gases*. Water is a liquid: air is a gas.

31. Liquid Substances.— Liquids have no shape of their own: the freedom of motion of their molecules is such that they at once take the shape of the vessel into which they are poured. Thus, water poured into a cup or bottle, at once takes the shape of the inside of the cup or bottle.

32. Mobile and Viscid Liquids.— In some liquids, such as alcohol or water, the molecules move very easily over one another. Such liquids flow readily, and are said to be *mobile*. In other liquids, such as tar or molasses, the molecules do not move over one another so easily. Such liquids do not flow readily, and are said to be *viscid.*

In viscid liquids the force of molecular attraction is stronger than it is in mobile liquids, and therefore prevents the molecules from moving over one another as easily as in mobile liquids, in which the molecules are not so strongly held together.

33. Gaseous Substances.—In the gaseous state the molecules can move over one another much more readily than they can in liquids, because they are further apart.

The atmosphere, which surrounds the earth, is formed mainly of two different gaseous substances. In the upper regions of the atmosphere, the air is much lighter than it is in the lower regions, because the lower layers, having to bear the weight of all the air that is above them, are compressed, and therefore made heavier.

Many liquids when heated will turn into the gaseous state. Gaseous bodies formed from liquids by the action of heat are called *vapors.*

SYLLABUS.

The solid substance ice, when heated, melts, and becomes a liquid. When the liquid is still further heated, it evaporates or passes off as a gas or vapor.

When ice is heated it liquefies, because the heat causes its molecules to get further apart than they were. The liquid when heated turns into a vapor, because the heat causes the molecules to get still further apart.

The molecules are nearest together in solids, and furthest apart in gases.

When a substance is heated, the heat causes the molecules to move away from one another.

Solid substances possess a definite shape. Liquids and gases have no shape: they at once assume the shape of the vessel in which they are kept.

In some solids the molecules are held together more powerfully than in others.

In fluid substances the molecules flow readily over one another. There are two kinds of fluids; viz., liquids and gases.

Liquids have no shape of their own, but take at once the shape of the vessel into which they are poured.

Mobile liquids flow very freely: viscid liquids do not flow freely.

The lower layers of the atmosphere are heavier than the upper layers, because gases are very compressible, and the weight of the upper layers packs the lower layers into a smaller space.

QUESTIONS FOR REVIEW.

Why will a piece of ice liquefy when heated? Why will water when heated turn into vapor?

Are the molecules of ice smaller than those of water or of vapor?

What is the force called that attracts or draws the molecules together? By what force are the molecules repelled or pushed apart?

In what three different conditions may substances exist?

How do solids differ from liquids or gases? Are the molecules of all kinds of solid substances held together with equal force? How can you prove this experimentally?

What two kinds of fluid substances are there? Why can neither liquids nor gases be made to retain any particular shape unless kept in vessels? Why are some liquids mobile and others viscid? Name some mobile liquids. Name some viscid liquids.

In which of the three conditions of matter are the molecules the furthest apart? In which are they the nearest together?

CHAPTER V.

FORCE AND MOTION.

34. Force is anything which makes a body begin to move, which stops its motion, or which changes the direction of its motion.

We have seen in Chapter III. that force is necessary in order to overcome the inertia of matter.

All natural phenomena are caused by force acting on matter.

35. Varieties of Force.—Force manifests itself in a variety of ways, and thus arise different varieties of force.

We have already mentioned the *force of gravity*, which causes unsupported bodies to fall to the earth; the *muscular force* of animals; the *force of heat*, which pushes the molecules of matter apart; the *force of molecular attraction*, which draws the molecules together; the forces of *magnetic and electric attraction and repulsion.* Besides these there are many other varieties of force.

36. Direction of the Force.

Experiment (20).—Place a book on a table; push the book. Observe that the book moves from you: pull it; observe that it moves towards you.

A bullet leaves a gun in the direction of the barrel, because the force of the powder acts to drive it in this direction.

When force acts on a body, and the body moves, the direction in which it moves depends on the direction in which the force acts.

37. The Point where the Force Acts.

Experiment (21).—Place a book on a table. Holding a ruler in the hand, place one end against the book and push. Observe that the kind of motion given to the book depends upon the part of the book touched by the ruler. If, for example, the ruler be placed against one end, exactly in the middle, the book will move straight forwards in the direction you are pushing; but if the ruler be placed nearer one end of the book than the other, although the book will still move forwards, yet it will, at the same time, move partly around.

The point of a body at which a force acts determines the kind of motion that is given to the body.

38. The Amount or Intensity of the Force.

Experiment (22).—Placing a book on a table as before, push it gently. Observe that it moves slowly. Then push it harder, and observe that it moves faster.

The amount or the intensity of the force determines the rapidity of motion given to a body.

39. Mass and Velocity.

Experiment (23).—Place a large and a small book on a table, and push each with the same force. Observe that the small book moves more rapidly than the large book.

All molecules of the same kind of matter have the same weight. The large book has more matter in it than the small one, that is, it has a greater number of molecules; and as each of these molecules requires a certain amount of force to move it, the large book must move more slowly than the small one. The quantity of matter or the number of molecules in any body is called its *mass*. The distance through which a body moves in a given time is called its *velocity*. Velocity means speed. When we say that a body has a velocity of three feet a second, we mean that it will move through a distance of three feet in one second.

To determine, therefore, the nature of the motion produced in a body by a force acting on it, we must know the direction in which the force acts, the point in the body at which it acts, and the intensity with which it acts. We must also know the mass of the body.

40. Momentum.—From the preceding experiments, we can see that there are two things upon which the amount of force, or the energy required to produce a given motion, depends; these are

1st. The mass of the body, and,

2d. The velocity of the body.

To determine, therefore, the amount of energy of motion that a moving body possesses, we must multiply the mass of the body by its velocity. This product is called the momentum.

By the momentum of a moving body we mean the quantity of motion it possesses.

Experiment (24).—Place a large cannon-ball on the floor near a small marble. Strike the cannon-ball with a mallet, and observe its slow motion. Strike the marble with the mallet with the same force as the cannon-ball was struck. Observe that it moves very rapidly.

Since the same amount of energy was imparted to each ball, the momentum, or the amount of energy of motion they possess, must be the same. In order, however, that the marble may have the same momentum as the cannon-ball, it must have a much greater velocity.

It is on account of the inertia of matter that bodies act as reservoirs into which energy may be put, or from which as much energy may be taken as has been put into the body.

41. Illustrations of Momentum.—A floating ship strikes the sides of a boat without injuring it: a floating log may crush the boat.

A ship, caught between two icebergs moving in opposite directions, is crushed as certainly as an egg-shell when trodden on.

A rain-drop scarcely bends the blade of grass on which it falls; a hail-stone may cut the leaves, or even branches, from trees; a rifle-bullet carries death in its path; a cannon-ball may pierce a thick plate of hardened steel.

When moving bodies meet, the shock is nearly the same whether both be moving, or one of the bodies be at rest. A man's skull is as certainly broken by being thrown from a galloping horse against a tree, as though he were at rest, and the tree struck him with a velocity sufficient to give it an amount of motion equal to that of the horse.

Swift skaters meeting in opposite directions may be fatally injured. Vessels colliding at sea, or trains of cars, on steam-railways, often cause frightful loss of life.

42. The Action of a Force not Affected by the Condition of Rest or Motion of the Body.—We know, by common experience, that a force acting on a body produces the same effect whether the body be at rest or in motion.

If, while in a rapidly-moving carriage or car, we drop a body, it strikes the floor directly underneath the place from which it fell. The floor does not move from under the body while the body is falling, because the body is moving forwards as rapidly as the car.

A mounted acrobat at a circus, in jumping through a hoop, does not jump forward, or he would be carried over the horse's head. He simply jumps up into the air, and his body moving forwards as fast as the horse, carries him through the hoop, and so he falls again on the back of the horse.

43. Varieties of Motion.—Bodies may move either in straight or in curved lines. Straight-lined motion is seen in a wagon driven by a horse; in a steamboat; or a train of cars. Curved-line motion is seen in the pendulum of a clock. A body moving around a fixed point, as, for example, a wheel moving on an axis, is said to have a *rotary motion.*

44. Direction of Motion Caused by more than One Force.

Experiment (25).—Let a pupil move a piece of chalk over a black-board so as to draw the line *A C*, Fig. 5. Let another pupil move the chalk from *A* to *B* so as to draw the line *A B*. Now, both holding the same piece of chalk, let the first try to move the chalk along the line *A C*, while the second, with the same force, tries to move it along *AB*. Observe that the chalk moves along the diagonal line *AD*.

When a force acts on a body in any direction, it causes the body to move in that direction. But a body cannot move in more than one direction at the same time. No matter, therefore, in how many different directions the forces may act, they can produce motion in one direction only. The direction in which the body moves depends on the direction in which the forces act. If they are acting on the same point in opposite directions, they may exactly balance each other, and the body will remain at rest. If they are acting at any angle, as in Fig. 5, the direction in which the body moves can be found by drawing the parallelogram *A B C D*. The body will move in the direction of its diagonal, *A D*, from *A* to *D*.

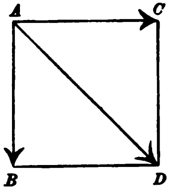


Fig. 5.—Resultant Motion.

SYLLABUS.

Force is anything which makes a body begin to move, which stops its motion, or which changes the direction of its motion.

All natural phenomena are caused by force acting on matter.

Some of the different kinds of force are the force of gravity; the muscular force of animals; the force of molecular attraction; heat, or the force of molecular repulsion; and the forces of magnetic and electric attraction and repulsion.

The direction in which a body moves depends on the direction in which the force acts that causes its motion.

The point of a body at which a force acts determines the kind of motion it causes.

The amount or intensity of the force determines the velocity of the motion given to the body.

The momentum of a moving body is the amount of energy of motion it has, and is equal to the mass of the body multiplied by its velocity.

By the mass of a body we mean the quantity of matter it contains: by the velocity we mean the distance through which the body moves in a given time.

The greater the mass of a moving body or the greater its velocity, the greater is the amount of energy of motion the body possesses.

The same effect is produced on a body by a force acting on it, whether the body is at rest or in motion.

There are different kinds of motion, such, for example, as straight-lined motion, curved-line motion, and rotary motion.

When several forces act on a body at the same time, they can produce motion in a single direction only.

QUESTIONS FOR REVIEW.

Define force. What is the cause of all natural phenomena?

Name some of the different ways in which force or energy manifests itself, and give examples of each.

Upon what does the direction in which a body moves depend? Upon what does the kind of its motion depend? Upon what does the velocity or speed of its motion depend?

Define mass. Define velocity.

Why should a body with a large mass, require more force to move it with a certain velocity than a body with a smaller mass?

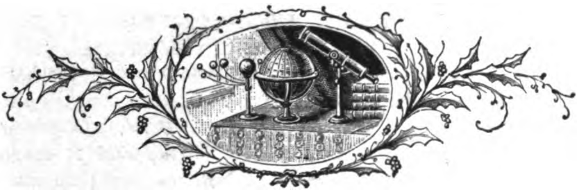
How can we determine the amount of energy of motion a body possesses?

Define momentum. State some familiar facts that illustrate the action of momentum.

Why does a body dropped to the floor of a rapidly-moving car strike the floor directly underneath the place from which it fell?

Name some of the different varieties of motion.

When two forces are acting on a body in directions at any angle to each other, how may the direction in which the body will move be ascertained?



CHAPTER VI.

THE MECHANICAL POWERS.

45. Machines.— When we wish to transmit force from one point to another, so as to alter its intensity, or its direction, or both, we employ a machine.

A machine is such an arrangement of parts as will enable us to transmit force from one point to another, so as to alter its direction, or intensity, or both.

The force used in moving a machine is called the *power*. The work to be done is called the *work*, *weight*, or *resistance*.

A pair of scissors is a good example of a simple machine. Here the power, which is the strength of the fingers, is applied at the handles, in a direction which causes them to come together. The work done is the cutting of some material placed between the blades.

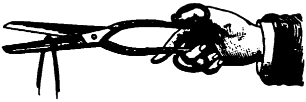


Fig. 6.—A Simple Machine.

46. The Principle of Velocities.

Experiment (26).— Support a thin rod, *A B*, Fig. 7, on the edge of a board or other fixed support at *F*. Then, since the part between

F and *B* is heavier than the part between *F* and *A*, the bar will move into the position shown at *A′ B′*. Observe that the distance *B B′*, through which the end *B* moves, is greater than the distance *A A′* through which the end *A* moves. If *F B* is twice as great as *F A*, then *B B′* will be twice as great as *A A′*. But the long end *B* moves through the arc *B B′* in the same time that the short end *A* moves through *A A′*; and since *B′ B* is twice as great as *A A′*, the end *B* must move twice as fast as the end *A*.

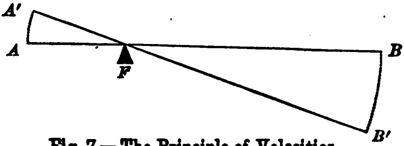


Fig. 7.—The Principle of Velocities.

Were the rod *A B* supported at its middle, it would be in equilibrium, because there is an equal quantity of matter on each side of the point of support: and it would remain in equilibrium, if we hung equal weights on at the ends *B* and *A*.

But with the rod supported as in Fig. 7, it will be found that one pound hung at *B* will balance two pounds hung at *A*. The bar will be in equilibrium, and the weights will balance, because the momentum or amount of energy of motion at either end is equal to that at the other end. Thus, the one pound at *B* has a velocity of two, hence its momentum is $2 \times 1 = 2$. The two pounds at *A* have a velocity of one, hence, also, the momentum is $1 \times 2 = 2$.

The rod *A B* moving about the point *F*, is in reality a simple machine. Power applied at either end will do work or overcome resistance at the other end.

If the power be applied at the long end of the bar, the weight moved will be greater than the power which moves it; but the weight will move less rapidly than the power.

If the power be applied at the short end of the bar, the weight moved will be less than the power which moves it; but the weight will move more rapidly than the power.

What a machine gains in power it loses in time, and what it gains in time it loses in power.

47.—Relation Between Power and Weight in any Machine.— We can easily determine the relation that exists between the power applied to the moving of any machine, and the work the machine can do; for, disregarding friction or fluid resistances, we need only notice the distance through which the power must be moved in order to cause a given movement of the weight.

If the power moves through say, two feet, in order to move the weight through one foot, then one pound will raise two pounds; but it will require twice as long as if the weight were raised directly.

If the power moves through one foot while the weight moves through two feet, then two pounds would be required to raise one pound; but it will raise it *twice* as rapidly as if it were raised directly.

48. No Energy Gained by a Machine.— When we observe that one pound hung to the bar at *B* will raise two pounds hung at *A*, it would appear as if some energy has been created by the machine. But this is not the case. *No more work can be done by any machine than that which has been expended in moving* *it.* In fact, friction and fluid resistances cause rather less work to be done by the machine than that originally put into the machine to move it.

Suppose, for example, that a man by exerting all his strength could just raise 100 lbs. If he should push down the end, *B*, of the bar, Fig. 7, with a force of 100 lbs., he could raise a weight of 200 lbs. hung to the bar at *A*; but to raise the 200 lbs. through one foot, he would be compelled to exert his strength at *B*, through two feet. Without the use of the lever, as this simple machine is called, he could only raise the 200 lbs. through the distance of one foot, by dividing them into two parcels of 100 lbs. each, and then lifting each parcel of 100 lbs. separately through one foot. But this would be exerting his strength of 100 lbs. through two successive feet, which is precisely what he does when he uses the lever.

Though no energy is gained by means of machines, yet their use is attended with great convenience. In the case just mentioned, the time required to pass from parcel to parcel is of course saved. Machines, too, often enable us to do work which would otherwise be impossible.

49. Simple Machines, Sometimes Called the Mechanical Powers.

—The most complicated piece of machinery is composed of various combinations of a number of simple machines, called the *mechanical powers.*

The mechanical powers are the lever, the wheel and axle, the pulley, the inclined plane, the wedge, and the screw.

The mechanical powers are all modifications of the lever, or of the inclined plane.

In what we shall say about simple machines, it is supposed that no force or energy is lost during its transmission through the machine.

50. The Lever.—The lever is a rigid rod or bar which moves about a fixed point called the *fulcrum.*

A force applied at one end raises a weight or overcomes a resistance at the other end.

There are three classes or kinds of levers. In the first class, Fig. 8, the fulcrum, *F*, is between the power, *P*, and the weight, *W*.

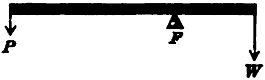


Fig. 8.—Lever of the 1st Class.

Examples of levers of the first class are found in a pair of scissors; in a crowbar, when used to raise blocks of stone; in the common balance for weighing; and in a pair of pincers.

In the second class, the weight, *W*, Fig. 9, is between the fulcrum, *F*, and the power, *P*.

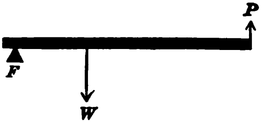


Fig. 9.—Lever of the 2d Class.

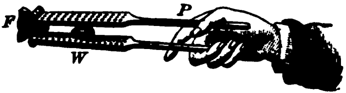


Fig. 10.—Lever of the 2d Class.

Examples of levers of the second class are found in nutcrackers, Fig. 10, where *W*, the nut to be cracked, is placed between the fulcrum, *F*, and the handles, *P*, where the power is applied. A door when opened by a hand applied to the knob is another example; the weight of the door is between the hinges, which act as the fulcrum, and the knob where the power is applied. A wheelbarrow is another example.

In the third class, the power, P, Fig. 11, is between the fulcrum, F, and the weight, W.

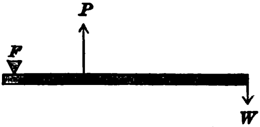


Fig. 11.—Lever of the 3d Class.

Fig. 12.—Sugar-Tongs.

Examples of levers of the third class are seen in the sugar-tongs, Fig. 12, and in the common foot-treadle.

51. The Arms of the Lever.—The shortest distance from the fulcrum to the direction in which the power acts is called the *arm of the power;* the shortest distance from the fulcrum to the direction in which the weight acts is called the *arm of the weight.* Thus, in Figs. 8, 9, and 11, $P\ F$ is the arm of the power, and $F\ W$ is the arm of the weight.

To determine the efficiency of the lever, divide the arm of the power by the arm of the weight; multiply the quotient by the power, and the product will give the weight the lever will raise. Thus, suppose, in Fig. 8, $F\ P$ is three times the length of $F\ W$, then how much weight will a power of five raise? $F\ P$ divided by $F\ W = 3$, and $3 \times 5 = 15$. That is, five pounds at P will raise fifteen pounds at W.

Problems.—(11.) If $F\ P$, Fig. 9, $= 4$ and $F\ W = 1$, how much weight at W will a power of ten pounds raise?

(12.) If FP, Fig. 11, $= 1$ and $FW = 4$, what weight will a force of ten pounds at P raise at W?

(13.) What relation must exist between the arms of a lever of the first class in order that ten pounds shall raise 1000 pounds?

(14.) In a lever of the third class, five pounds are required to raise a weight of one pound; what are the relative lengths of the arms?

52. The Wheel and Axle.—In the wheel and axle, a power applied at the circumference of a wheel raises a weight attached to a rope wound around the axle. In the windlass, which is one form of the wheel and axle, the wheel is replaced by a handle at *W*, Fig. 13. Since one turn of the handle, *W*, raises the weight of the basket, *B*, the length of the rope wrapped once around the axle, *A*, it is evident that one pound applied at the wheel or handle, *W*, will raise as many more pounds hung at the axle, as the circumference of the wheel is greater than the circumference of the axle.

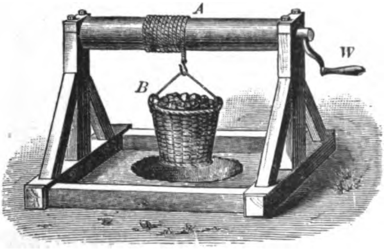


Fig. 13.—The Windlass.

Problem (15).—The circumference of the wheel, Fig. 13, is twenty feet, and the circumference of the axle is three feet; how much weight would a force of fifty pounds applied at the handle, *W*, raise in the basket, *B*?

Water-wheels, and steering-apparatus for vessels are examples of this simple mechanical power.

53. The Pulley.—The pulley consists of a wheel turning on its axis, and having an edge over which a flexible band or rope passes.

Pulleys are *fixed* or *movable*. In the fixed pulley, the only advantage gained is in the change of direction. In a movable pulley, such as is shown in Fig. 14, if the power, *P*, move through two feet, it will raise the weight, *W*, attached to the block, *A*, through but one foot, since the rope is pulled both from *D* and *C*.

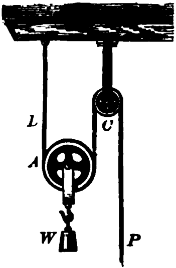


Fig. 14.
A Movable Pulley.

Problem (16).—In a pulley such as shown in Fig. 14, what power would be required to raise a weight of one ton?

54. The Inclined Plane.—Instead of raising a weight directly through a given height, it may be raised gradually through that height by rolling it up an *inclined plane*.

An application of the inclined plane is seen in Fig. 15, where a barrel is raised from a pavement to the door of a warehouse by rolling the barrel up the inclined plane.

Fig. 15.—An Inclined Plane.

The greater the length of the plane as compared with its height, the smaller the force required to raise the weight; for, if the length of a plane be four times as great as its height, then, since the power is applied through a distance four times as great as the distance through which the weight moves, a force of one pound will raise four pounds up the plane.

55. The Wedge.—The wedge is a modified form of inclined plane, in which, instead of moving the weight up the plane, the plane is moved under the weight. The wedge is used when great force is to be exerted in a small space, such, for example, as in splitting wood or stone, or in pressing oils or juices from seeds. The edges of such cutting-tools as scissors, knives, chisels, hatchets, and razors are forms of wedges.

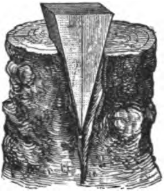


Fig. 16.
The Wedge.

56. The Screw.—The screw is another modification of the inclined plane, and is employed as a mechanical power whenever a great force is to be exerted in a small space. The copying-press, Fig. 17, is an example of a screw used as a mechanical power. The power, acting at the handle, *P*, exerts a pressure against anything placed beneath the plate, *W*, connected to the end of the screw. One turn of the screw will advance the plate, *W*, through a distance equal to the distance between two consecutive threads. If the threads be the one-tenth of an inch apart, and the power move through a circle of twenty-four inches, the plate will advance

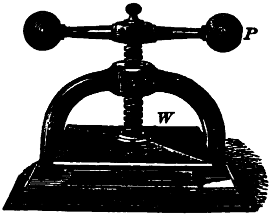


Fig. 17.—A Copying-Press.

through the one-tenth of an inch, or will move through a distance two hundred and forty times as great as the power. Therefore one pound at *P* will move a weight of two hundred and forty pounds at *W*.

Problem (17).—In the case just mentioned, how many pounds must be applied at *P* in order to cause *W* to exert a pressure of one ton?

SYLLABUS.

A machine is such an arrangement of parts as will enable us to transmit force from one point to another, so as to alter its direction, or its intensity, or both.

The force used in moving a machine is called the power. The work to be done is called the work, weight, or resistance.

If in any machine the distance through which the power moves is greater than that through which the weight moves, the power will move a weight greater than its own; but it will move it more slowly. If the distance through which the power moves is less than that through which the weight moves, then the power will move a weight less than its own; but it will move it more rapidly.

Therefore, what a machine gains in power it loses in time, and what it gains in time it loses in power.

No more work can be done by any machine than that expended in working or moving it.

The mechanical powers are the lever, the wheel and axle, the pulley, the inclined plane, the wedge, and the screw.

In a lever of the first class, the fulcrum is between the power and the weight. In the second class, the weight is between the power and the fulcrum. In the third class, the power is between the weight and the fulcrum.

To determine the efficiency of the lever, divide the arm of the power by the arm of the weight; multiply the quotient by the power, and the product will be the weight the lever can raise.

The greater the circumference of the wheel, in the wheel and axle, and the smaller the circumference of the axle, the greater the effect of the power.

Pulleys are either fixed or movable.

Instead of raising a weight directly through a given height, it may be raised gradually through that height by rolling it up an inclined plane.

The wedge and the screw are modifications of the inclined plane. They are employed where a great force is to be exerted in a small space.

QUESTIONS FOR REVIEW.

Define machine. Define power and weight. Give an example of a simple machine.

Where must a straight bar be supported in order that a pound hung at one end will balance three pounds hung at the other end?

How may the relation that exists between the power applied to the moving of any machine and the work the machine can do, be easily determined?

If no energy is gained by a machine, explain how a power of one pound, can be made to lift a weight of three pounds.

Name the mechanical powers. Of which two of them are all the others modifications?

Into what three classes may levers be divided? Describe those of each class.

To which class does each of the following simple machines belong; viz., a crowbar, a wheelbarrow, a pair of scissors, a pair of nut-crackers, a door opened by a hand applied at the knob, a pair of sugar-tongs, a pair of pincers, and the common foot-treadle?

What is meant by the arms of a lever? State the rule for determining the efficiency of the lever.

Describe the wheel and axle. Upon what does the efficiency of the wheel and axle depend?

Describe the movable pulley.

What is the use of the inclined plane? Upon what does its efficiency depend?

Describe the wedge. Describe the screw. For what purposes are the wedge and the screw generally applied?

CHAPTER VII.

GRAVITATION.

57. Force of Gravity.— Unsupported bodies fall to the earth, because the earth attracts or draws them towards it. We do not know the cause of gravity, or the attraction of gravitation, as this force is called; but just as the molecules of matter have an attraction for one another, which draws them together, so we find that all masses of matter have an attraction for one another.

This attraction is greater the greater the mass. When a ball is allowed to fall from the hand, it falls to the earth, because the earth attracts or draws it; the ball also draws the earth up towards it; but since the quantity of matter in the earth is so much greater than the quantity in the ball, we cannot see the motion of the earth, but only see the motion of the ball.

58. Cause of Weight.— If we hold the ball in the hand, we can feel the earth pulling the ball towards it; that is, the ball feels heavy. This attraction is the cause of weight. The larger the ball, or the more matter it contains, the greater its weight; for, as we have already said, the attraction increases as the mass or quantity of matter.

59. English and French Systems of Weight.— The unit of weight both in this country and in England is the *pound*. Unfortunately, the pound is of two distinct kinds; viz., the *pound avoirdupois* and the *pound troy*. The grains are alike in both of these pounds, but the other subdivisions are different. The avoirdupois pound contains 7000 grains, and the troy pound contains 5760 grains; in the former there are 16 ounces, and in the latter 12 ounces.

In France, the unit of weight is the *gramme*, and its multiples and subdivisions. The gramme is the weight of a cubic centimetre of water at the temperature of its greatest weight; viz., at 39.2° F., and is equal to about 15.432 grains troy. The following table gives the names and values of these multiples and subdivisions:

		Grammes.		*Grains.*		*Ounces troy = 480 Grains.*
1 Kilogramme	=	1000	=	15432.34	=	32.15072
1 Hectogramme	=	100	=	1543.23	=	3.21507
1 Decagramme	=	10	=	154.32	=	0.32150
1 Gramme	=	1	=	15.43	=	0.03215
1 Decigramme	=	0.1	=	1.543	=	0.00321
1 Centigramme	=	0.01	=	.1543	=	0.00032
1 Milligramme	=	0.001	=	.0154	=	0.000032

Problems—(**18.**) In one pound avoirdupois, how many kilogrammes? (**19.**) How many kilogrammes are there in one pound troy? (**20.**) How many milligrammes are there in one grain? (**21.**) How many centigrammes are there in one grain? (**22.**) How many pounds avoirdupois are there in 25 kilogrammes? (**23.**) How many pounds avoirdupois are there in 1000 grammes?

In order to understand the effects of gravity, we must, as with any other force, ascertain, 1st. *The direction in which it acts;* 2d. *Its point of application*, and 3d. *Its intensity.*

60. The Direction of Gravity.—The attraction of the earth draws bodies directly towards its centre, that is to say, it causes them to fall in a vertical line. A vertical line is one at right angles or perpendicular to a water surface. A horizontal line is one at right angles to a vertical line, or one which extends in the same direction as a water surface. In Fig. 18, the plumb-line is not supported directly by the hand, but by the string. Gravity acting on the weight, *W*, causes it to come to rest so that its lower end points directly towards the earth's centre. Since the string comes to rest in a vertical direction, this must be the direction in which gravity would cause an unsupported body to fall. If gravity acted in some other direction, the weight would come to rest in that direction.

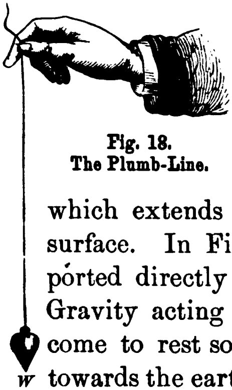


Fig. 18.
The Plumb-Line.

61. The Point of Application of Gravity, or the Centre of Gravity.—As gravity acts on each of the molecules, there must be as many separate downward pulls as there are molecules. Each of these pulls acts vertically downwards. A few of them are shown at *a*, *b*, *c*, *d*, *e*, and *f*, Fig. 19. There is, however, in every body a point where all these separate pulls may be considered as being collected. This point is called the *centre of gravity*. In Fig. 19, the centre of

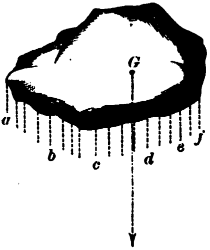


Fig. 19.
The Centre of Gravity.

gravity is shown at *G*. The centre of gravity, therefore, is the point in the body at which the force of gravity may be considered as acting; that is to say, it is the point of application of gravity.

62. To Find the Centre of Gravity.

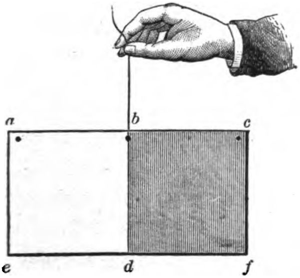


Fig. 20.—Method of Finding the Centre of Gravity.

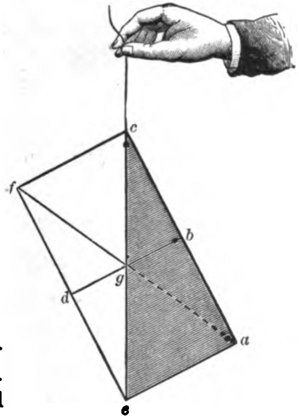


Fig. 21.—Method of Finding the Centre of Gravity.

Experiment (27).—In a rectangular piece of tin, bore holes at *a*, *b*, and *c*. Attach a piece of string at *b*, and hold as shown in Fig. 20. When the plate is at rest, draw the line *b d* in the direction of the string. Now attach the string at *c*, and, holding as shown in Fig. 21, draw the line *c e* in the direction of the string. The point *g*, where the line *bd* is cut by the line *c e*, will be the centre of gravity of the plate.

63. A Body Supported at its Centre of Gravity will be at Rest or in Equilibrium.—Since the plate of tin is free to move, and it comes to rest in the position shown in Fig. 20, the shaded portion, *b c d f*, must be of the same weight as the unshaded portion, *a b d e*; for, if they were not of equal weights, the heavier side would fall. So in Fig. 21, the shaded portion, *c e a*, is of equal weight to the unshaded part, *c e f*.

A body supported at its centre of gravity will, therefore, remain at rest, because its weight will be equal on all sides of the point of support.

64. Equilibrium of Bodies Supported on an Axis.

Experiment (28).—Cut a disc from a piece of stiff card-board, and, running a large needle through it at *S*, hold it as shown as Fig. 22. Make the hole at *S* large enough to allow the disc to move freely over the needle. Observe that if the disc be moved to the left or to the right, and then allowed to fall, it will, after a few swings, again take the position shown in the figure, where *G*, the centre of gravity of the disc, is in the vertical line which passes through the point of support, *S*.

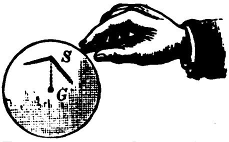


Fig. 22. Stable Equilibrium.

When the centre of gravity is in the same vertical line as the point of support, the disc has no tendency to move, because there is an equal weight of matter to the right or the left of the vertical line. But if it be moved out of this position, say to the right, there will be a greater weight of matter on the right than on the left, so that, when no longer held, the heavier side falls and the lighter side rises until the disc again takes the position shown in Fig. 22.

Therefore a body supported on an axis on which it can freely turn, will not be in equilibrium unless its centre of gravity is in the vertical line which passes through its point of support.

This condition can be fulfilled by three different positions of the centre of gravity; viz., the centre of gravity may be above the point of support; the centre of gravity may be at the point of support; or the centre of gravity may be below the point of support.

65. Stable Equilibrium.—When the centre of gravity is below the point of support, as in Fig. 22, the body is in that kind of equilibrium that is called stable. Any motion given to the body causes its centre of gravity to rise, and to do this we must lift a part of the weight of the body.

66. Unstable Equilibrium.

Experiment (29).—Hold the disc as shown in Fig. 23, with the point of support, *S*, below the centre of gravity, *G*, but in the vertical line which passes through the centre of gravity. Observe that the slightest motion of the disc to the right or to the left will cause the side towards which it is moved to become heavier than the other. When this is done, no further pushing is necessary. Gravity will then cause the centre of gravity to fall as low as possible, and the disc will take the position shown in Fig. 22.

Fig. 23.
Unstable Equilibrium.

Because so slight a motion will disturb the equilibrium of the disc when the point of support is below the centre of gravity, as in Fig. 23, the body is said to be in *unstable equilibrium.*

67. Neutral Equilibrium.

Experiment (30).—Support the disc at its centre of gravity, *G*, as shown in Fig. 24. Observe that no matter how the disc is turned, it will remain in equilibrium, since no motion of the body can change the position of the centre of gravity.

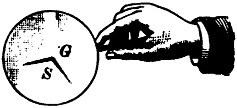


Fig. 24.
Neutral Equilibrium.

When the point of support is at the centre of gravity, the body is said to be in *neutral equilibrium.*

68. Equilibrium of Bodies Resting on a Horizontal Surface.—When any part of a body rests on a horizontal surface, so that it has more than one point of support, it is not necessary that the centre of gravity should be directly above any one of these points of support. It is sufficient if the vertical line passing through the centre of gravity falls within the base on which the body rests. As before, the equilibrium may be stable, unstable, or neutral.

When the centre of gravity is as low as it can get, the body is in stable equilibrium. The wider the base and the lower the centre of gravity, the greater the stability.

69. Illustrations.—A high stool is more easily overturned than a low stool. A stool whose legs are far apart is harder to overturn than one whose legs are near together. A step-ladder is made broadest at the base so as to give it greater stability.

A wagon loaded with hay is more easily upset than one loaded with stone, because in the former the centre of gravity is higher than in the latter.

A person standing with his feet near together is more easily upset than if he places his feet wide apart. Monuments are always made broad at the base, so as to give them greater stability.

In carrying a load on the head, we hold ourselves upright, so that the centre of gravity may fall somewhere between our feet. When the load is carried on the back, we lean forwards for the same reason. In stooping forwards to pick up anything from the floor, we bend a part of our body backwards, so as to keep from falling. To prove this, stand a person with his heels close to a wall. He cannot now, without falling, bend forwards sufficiently to pick up any object from the floor, because the wall prevents him from throwing part of his body backwards, so as to balance the head and arms when he moves forwards.

Passengers are safer in a small boat if they remain seated; for, if they stand up, the centre of gravity is raised, and the boat is more easily upset.

70. Falling Bodies.— When a body first begins to fall, it moves very slowly, and its motion can easily be followed by the eye; but moving faster and faster, it soon becomes impossible to follow it. When a boy allows a ball to drop from his hand, he can shortly afterwards easily catch it again before it reaches the ground; but if he waits a little longer, he reaches after it in vain.

That a body should fall with a constantly increasing rapidity is a consequence of inertia. The earth is constantly attracting the body, that is, giving it motion; and since the body does not lose the motion previously acquired, and the earth is constantly giving it more motion, its velocity must constantly increase.

Hence, the greater the distance through which a body falls the greater the velocity it acquires.

71. Illustrations.— A rock rolled down the side of a hill begins to move very slowly; but when it nears the bottom, its velocity is very great.

One can jump from a table without injury; a jump from a high window would probably result in broken bones; while a fall from a balloon high in the air would cause the person to be dashed to pieces.

72. Velocity of Fall Independent of the Weight.

—*Heavy bodies fall with the same velocity as light bodies.*

The above statement seems at first thought contrary to experience, since we know that a piece of gold leaf will fall less rapidly to the ground than will the same amount of gold in the shape of a ball. But in this case, it is the resistance of the air that causes the difference in velocity. The gold leaf, in order to fall through the air, pushes more of the air out of its way, and therefore loses more of its motion, than the gold ball. In a vacuum or empty space, such as might be obtained in the tube *B*, Fig. 25, the gold leaf is found to fall with the same velocity as the ball.

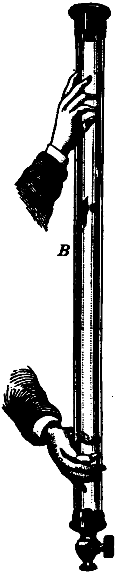


Fig. 25.—Bodies Falling through an Empty Space.

73. The Pendulum.

Experiment (31).—Attach a ball or weight of any kind to a string supported as shown at *a*, Fig. 26. When at rest, the ball will be directly under the point of support, as shown on the right of the figure. It will then, like the disc seen in Fig. 22, be in stable equilibrium. Now move the ball, *b*, until it assumes the position shown at *c*. On letting the ball fall, observe that gravity pulls it down to *b*. It does not, however, stop when it reaches *b*, because the motion it has acquired in falling carries it to *d*. Observe that when it reaches *d*, it again moves towards *b* and *c*, and continues, for some time, swinging between points to the right and left of *b*.

The ball supported by the string at *a* forms what is known as a *pendulum*. A swing of the pendulum from *d* to *c* or from *c* to *d*, is called an *oscillation.*

Experiment (32).—Cause the pendulum to swing, and watching, observe that it moves through smaller and smaller distances on either side of the vertical, and finally comes to rest. Now move it again, and observe that it takes as long to move through the small arc, when it has nearly stopped moving, as it does to move through the longer arc, near the beginning of its motion. In this experiment, the pendulum must not be moved through too great an arc.

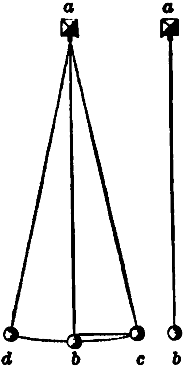


Fig. 28.
The Pendulum.

In the same pendulum, as much time is required to make an oscillation through a small arc as is required, within certain limits, to make an oscillation through a large arc.

Experiment (33).—Make two pendulums, one shorter than the other. Observe that the oscillations of the shorter pendulum are made in a shorter time than those of the longer pendulum.

A shorter pendulum oscillates more rapidly than a longer pendulum.

The pendulum is employed in clocks. By its motion the wheel-works of the clock are kept moving. The pendulum is kept moving by the action of a spring or weight.

SYLLABUS.

By the force of gravity is meant the force that causes bodies to fall to the earth. All masses exert an attractive force for one another, which causes them to try to come together.

The weight of a body is caused by the attraction which the earth has for it.

The unit of weight in this country is the pound. In France and Europe generally, the unit of weight is the gramme.

The pound avoirdupois contains 7000 grains: the pound troy contains 5760 grains: the gramme contains 15.432 grains.

Gravity acts in the direction of a vertical line, as is shown by means of a plumb-line.

The point in any body at which gravity may be considered as acting, is called the centre of gravity.

The centre of gravity may be regarded as a point where all the weight of the body is collected.

The centre of gravity of any body may be found where two lines of direction cross each other.

A body supported at its centre of gravity will be at rest or in equilibrium.

A body supported on an axis around which it is free to turn, will not be in equilibrium unless its centre of gravity lies in the vertical line which passes through its point of support. Such a body may be in stable, in unstable, or in neutral equilibrium.

When bodies resting on a horizontal surface have several points of support, they will be in equilibrium if the vertical line passing through the centre of gravity fall within the base on which the body rests.

The broader the base on which a body rests, and the lower its centre of gravity, the more stable its equilibrium.

The greater the distance through which a body falls, the greater its velocity.

Heavy bodies fall with the same velocity as light bodies, but the resistance of the air sometimes causes a difference in their velocities.

In the same pendulum, the same time is required to make an oscillation through a small arc as is required, within certain limits, to make an oscillation through a large arc.

A short pendulum oscillates more rapidly than a long pendulum.

QUESTIONS FOR REVIEW.

Define force of gravity. Do all masses attract one another? How does gravity cause weight?

Describe the English and the French systems of weight.

In what direction does the force of gravity act? How can this be proved experimentally?

Define centre of gravity. How may the centre of gravity of a body be found experimentally?

Why should a body supported at its centre of gravity be at rest?

When will a body supported on an axis around which it is free to move, be in stable equilibrium? When will it be in unstable equilibrium? When will it be in neutral equilibrium?

When will a body resting on a flat surface, so as to have more than one point of support, be in equilibrium?

Give examples of bodies being in stable equilibrium because their bases, or the portion on which they rest, are broadened.

Give examples of bodies being in very stable equilibrium because their centre of gravity is near the base.

Why should a body acquire a gradually increasing velocity while falling? Give some instances of such gradually increasing velocities.

Why does the resistance of the air cause a piece of gold leaf to fall more slowly than a golden ball? How can you prove this experimentally?

Define pendulum. Define oscillation of a pendulum. Are the smaller oscillations of a pendulum made in any shorter time than the larger ones?

Which oscillates the more rapidly, a long pendulum or a short one?

CHAPTER VIII.

SOME PROPERTIES PECULIAR TO SOLIDS.

74. Some Properties Peculiar to Solids.—The solid condition of matter is characterized by certain properties peculiar to it. The more important properties peculiar to solids are *malleability*, *ductility*, *hardness*, *brittleness*, *tenacity*, *solid elasticity*, and *crystalline form.*

75. Malleability.—Substances are said to be malleable, if they can be beaten or rolled out into thin sheets. Nearly all the metals are malleable. Gold, lead, silver, tin, and copper are very malleable. Gold, as we have seen, can be beaten into leaves so thin that it requires about 300,000 to be piled together to make a pile an inch thick. Some metals are malleable only to a limited extent, and, if hammered too much, will crack or tear.

76. Ductility.—Substances are said to be ductile if they can be drawn out into wire. Most of the malleable metals are ductile, but not to the same extent that they are malleable. Platinum, silver, iron, and copper are very ductile.

In making wire, the metal, as, for example, a bar of iron or copper, is reduced in size at one end, so as to enter a hole in a plate of hardened steel. It is then seized in a pair of strong nippers, and drawn with great force through the plate. As it passes through, it is of course reduced in size to the size of the opening. By passing it successively through smaller and smaller holes, it at last acquires the desired size. Melted or softened glass has great ductility.

Experiment (34).—Hold a thin piece of glass tubing in the flame of a Bunsen burner (Fig. 61, p. 132). Keep turning the tube while heating, so as to heat all sides evenly. When soft, draw the two ends apart with a slow, steady motion. A glass wire or thread will be formed.

77. Hardness.—Substances are said to be hard if they resist being worn or scratched by others. Diamonds are the hardest substances known. They can cut or scratch any other substance. They are often employed for cutting glass.

When two substances are rubbed together, the softer of the two is scratched by the harder. Thus, glass will scratch marble, and, therefore, is harder than marble; but the diamond will scratch glass, and, therefore, the glass is softer than the diamond.

Some substances possess the valuable property of having their hardness altered by heat. Thus, if steel, heated to about redness, is suddenly cooled by being plunged into cold water, it becomes hard and brittle. If, however, it be heated, and then allowed to cool slowly, it becomes soft, ductile, and malleable.

From its great hardness, steel is used for making cutting-tools, such as knives, saws, planes, chisels, augers, etc. In order to be able to forge these articles, the steel is first softened, and, when the desired shape is obtained, they are afterwards hardened.

78. Brittleness.—A substance is said to be brittle if it is easily broken into pieces. Brittleness is nearly the opposite of malleability. Most hard substances are brittle, such, for example, as hardened steel and glass.

79. Tenacity.—A substance is said to be tenacious if it resists any force tending to pull it apart.

It is the force of molecular attraction that makes substances tenacious. Bodies differ in their tenacity, because the molecules in some substances are attracted to one another with much greater force than in others.

Iron and steel are very tenacious. Copper is less tenacious than silver, but more tenacious than zinc or lead. Many animal or vegetable substances are very tenacious, such as silk, cat-gut, hempen or linen thread. Many kinds of wood are very tenacious.

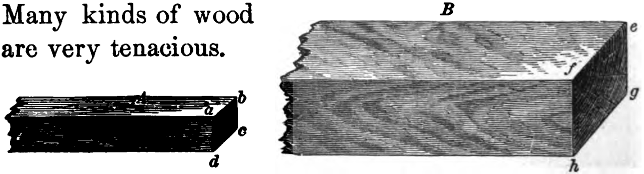


Fig. 27.—Influence of Sectional Area on Tenacity.

The tenacity of a beam or bar of wood, or, in fact, of any substance, increases with its breadth and depth. Thus, the bar *A*, Fig. 27, is more easily pulled apart than the bar *B*. If the end *a b c d* of the bar *A* have but one-fourth the area as the end *f e h g* of the bar

B, *A* will have but one-fourth the tenacity of *B*, provided they are both of the same substance.

80. Limits of Size of Structures.—By increasing the dimensions of any bar or beam, we can increase its tenacity; thus, by making one bar twice as broad and twice as deep and twice as long as another, the area of its cross-section, and hence its tenacity, will be increased four times, but its weight will be increased eight times. If we treble the dimensions of the bar, we make it $3 \times 3 = 9$ times stronger, but $3 \times 3 \times 3 = 27$ times heavier. If we make the dimensions eight times greater, we increase the tenacity $8 \times 8 = 64$ times, while we increase the weight $8 \times 8 \times 8 = 512$ times.

There is a limit, therefore, to the size which any structure can have. Even the most tenacious material, if made into too large a beam, would be broken by its own weight, since the strength or tenacity increases with the square of the dimensions, while the weight increases with the cube of the dimensions.

81. Elasticity of Solids.—A substance is said to be elastic if it possesses the power of returning to its original shape after being compressed, stretched, bent, or twisted.

Solids manifest elasticity when compressed, stretched, bent, or twisted.

Bodies vary greatly in their elasticity. India-rubber is elastic to a considerable extent; but it is not as elastic as glass or ivory, for, if stretched much or often, it permanently increases in length; while ivory or glass may, within small limits, be bent almost indefinitely without changing their forms. Billiard balls retain nearly their original polish after long use. Steel is very elastic; a well-tempered steel sword may be bent double, and yet will regain its former shape.

Experiment (35).— Allow an ivory or glass ball to fall from a height on a slab of marble. Observe that the ball rebounds instantly to nearly the height from which it fell. Wet the slab of marble and lay the ball gently on it; on removing the ball, a small dried spot will be seen on the slab where it was touched by the ball; now drying the ball allow it to fall again on the slab. Observe that the dried spot is larger than before, showing that the marble and the ball have changed their shape. It is the elasticity developed by this change of shape that causes the rebound of the ball.

Practical applications of elasticity are seen in the common bow and arrow; in various springs, such as those used in carriages, mattresses, sofas, and chairs; and in clocks and watches.

82. Crystalline Form.— We recognize an animal or a plant by a certain form peculiar to it. In the same way many lifeless substances occur in forms, called crystals, peculiar to them. Although in most solids these crystals are too small to be seen, yet they nearly always exist. For example, snow is composed of crystals of beautiful star-like shapes.

Experiment (36).— Place a quarter of a pound of common alum in as much hot water as will completely dissolve it. Strain the solution through a piece of muslin, and pour the clear liquid into a cup or bowl, in which has been placed a piece of rough stone wrapped with colored yarn. Set the liquid aside in a quiet place over night, and in the morning beautiful shining crystals will be found covering the stone. By slipping a thin knife under the stone, it may be separated from the bottom of the cup or bowl.

SYLLABUS.

Some of the more important properties peculiar to solids are malleability, ductility, hardness, brittleness, tenacity, solid elasticity, and crystalline form.

Substances are malleable, if they can be rolled or hammered out into thin sheets. They are ductile, if they can be drawn out into wire. Gold, lead, silver, tin, and copper are very malleable. Platinum, silver, iron, and copper are very ductile.

Substances are hard, if they resist being scratched or worn by others. The diamond and hardened steel are very hard.

When certain substances, such as steel, are heated to redness and then suddenly cooled, they become hard and brittle; but when heated and then slowly cooled, they become soft, malleable, and ductile.

A substance is brittle, if it is easily broken in pieces. A substance is tenacious, if it resists a force tending to pull it apart. Iron and steel are very tenacious.

The greater the area of cross-section of a bar, the greater its tenacity.

There are certain limits to the size of any structure, which, if exceeded, will cause the structure to fall apart by its own weight.

A substance is elastic, if it possesses the power of returning to its original shape after being compressed, stretched, bent, or twisted.

Solids manifest elasticity when compressed, stretched, bent, or twisted.

Most solids have a shape or crystalline form peculiar to them.

* * *

QUESTIONS FOR REVIEW.

Name the properties peculiar to solids.

Define malleability. Name some very malleable substances.

Define ductility. Name some substances that can be drawn out into thin wires.

Describe the process of wire drawing.

Define hardness. Name some hard substances. What is the hardest substance known?

Describe the process by means of which steel may be rendered hard and brittle.

How may steel be rendered soft, ductile, and malleable?

How are these properties utilized in the manufacture of steel tools?

Define brittleness. What kind of substances are generally brittle? Give some examples.

Define tenacity. Name some tenacious metals. Name some tenacious animal substances. Name some tenacious vegetable substances.

How may the tenacity of a beam or bar be increased?

Why cannot structures be increased indefinitely in size?

If the dimensions of a beam be increased sixteen times, how much will its tenacity be increased? How much will its weight be increased?

Define elasticity. Under what circumstances do solids manifest elasticity? How does the elasticity of India-rubber differ from that of ivory? Name some practical applications of elasticity.

What is meant by crystalline form?

How may crystals of alum be obtained?

CHAPTER IX.

COHESION AND ADHESION.

83. The Force of Molecular Attraction.

Experiment (37).—Draw a piece of chalk over a black-board. Observe that small particles become separated from the chalk and cling to the black-board. Press the chalk lightly on the board while drawing a line, and then press more firmly. Observe that, in the latter case, more of the chalk adheres to the board than in the former, and that therefore the line is broader. Force is evidently required to tear the particles from the chalk.

The force which causes the particles of the chalk to cling to the black-board, or to cling together, is the same, and is the force of molecular attraction. The chalk clings to the black-board, because there is an attraction between the molecules of the chalk and the molecules of the black-board.

The particles of the chalk cling together, because there is an attraction between the molecules of the chalk.

When the force of molecular attraction draws together molecules of the same substance, it is called the *force of cohesive attraction*, or simply *cohesion.* Thus, the molecules of the chalk cohere.

When the force of molecular attraction draws together molecules of different substances, it is called the force of *adhesive attraction*, or simply **adhesion.** Thus, the molecules of the chalk adhere to the molecules of the black-board.

84. Cohesion.—Cohesion, or the attraction between molecules of the same kind of matter, is the cause of tenacity. Cohesion varies very greatly in different substances. In some, the molecules are held together with very great force, while in others, they are held with very feeble force. In iron and steel, the cohesion is great; in soft butter or putty, it is small.

The force of cohesive attraction appears to act at very small distances. Broken glass or crockery do not cohere when the broken edges are pressed firmly together, probably because we cannot force the molecules sufficiently near together. But this is not true of all substances. Two glass plates, if very smooth and clean, will, if pressed firmly together, cohere with such force as to render it impossible to separate them without fracture. An importation of large plate-glass mirrors was once ruined in this way. The mirrors were packed with the unsilvered sides of the glass touching each other, and, when unpacked, were found to cohere so strongly that they could not be separated. Two clean, freshly-cut surfaces of lead will also cohere if pressed firmly together.

Experiment (38).—Cast two cylinders of lead with wire hooks in one end of each. With a sharp knife make flat the end of each cylinder in which there is no hook, and scrape it smooth and bright. Press the freshly-cut surfaces firmly together, and observe that they will cohere with sufficient force to support a heavy weight attached to the end of the lower cylinder, as shown in Fig. 28. To succeed with this experiment, the surfaces must be bright, smooth, and clean; therefore, avoid touching them with the hands.

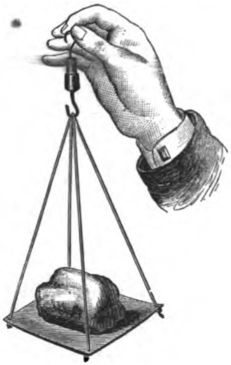


Fig. 28.
The Cohesion of Lead.

85. Cohesion of Liquids.—Liquids possess less cohesion than solids. Their molecules move so easily over one another that we might think they had no cohesion whatever. They do, however, cohere. A drop of dew on a smooth leaf is almost rounded like a ball. Did not the molecules of water cohere, the force of gravity would cause the water to spread out in a thin layer over the whole surface of the leaf.

Experiment (39).—Half fill a wine-glass with water. Pour half a teaspoonful of castor-oil on the water, but do not let the oil touch the sides of the glass. Now pour alcohol gently into the glass until a bulk of about one-third that of the water is added. Let the alcohol enter the glass from the sides. With a rod stir the liquid gently, without touching the oil. Let the liquid come to rest, and observe that the oil floats near the middle of the glass, in the shape of a sphere. If the mass of oil appear flat, add a little alcohol or water until the spherical shape is seen. The cohesion of the oil causes its molecules to collect around a centre, and thus take a globular shape.

86. Adhesion.—Adhesion is the attraction between molecules of different kinds of matter. Solids, liquids, and gases all exhibit the phenomena of adhesion.

87. Examples of Adhesion between Solids.—Mortar adheres to bricks or stones, and glue to pieces of wood, and binds them together; paint adheres to wood and ink to paper; paste adheres to the walls of a room and to wall-paper, and holds it on the walls: the same is true of envelopes and postage-stamps.

Blacking adheres to boots and shoes, as does also mud or dirt; dirt adheres to the clothes or to the hands or face; butter adheres to bread. The friction between two surfaces is also increased by their adhesion.

88. Examples of Adhesion between Solids and Liquids.—A clean hand is wetted when plunged into water, because the water adheres to the hand; but if greased, the water scarcely adheres at all. Water adheres to our clothes and wets them, but can readily be shaken off from some kinds of cloths, called water-proof stuffs, to which it adheres but slightly. The hand is not wetted when dipped into mercury. Many solids when thrown into liquids, as, for example, sugar into water, become changed into liquids. This change is called solution, and is caused by the adhesion between the solid and the liquid.

89. Capillarity.

Experiment (40).—Plunge a lamp-chimney into a vessel filled with water. Observe that the water stands at the same level inside and outside the chimney.

Experiment (41).—Hold a towel or handkerchief over the water so that one end dips in the water. Observe that the water rises in the handkerchief, and wets it far above the level of the water in the vessel.

The water rises in the towel or handkerchief and wets it, because it is drawn up into the cloth by adhesion. The walls of the lamp-chimney, if clean, also draw the water towards them; but the water inside the chimney is too heavy to be drawn very high. Observe that the surface of the water in the chimney is not exactly level, but is slightly drawn towards the walls both on the inside and outside, as is seen at *A*, in Fig. 29.

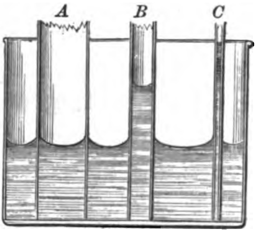


Fig. 29.
The Liquid Wets the Tube.

If a narrow tube, such as *B*, Fig. 29, be plunged into water, the level inside will be much higher than that on the outside, because the weight of the water in the tube is much smaller and the force of adhesion can raise it much higher. In a still narrower tube, as *C*, Fig. 29, the liquid will mount still higher, for the same reason.

If the liquid does not wet the tube, then there is no force to draw it towards the tube, and the cohesion of the liquid will draw it from the walls.

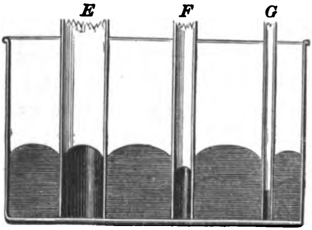


Fig. 30.
The Liquid does not Wet the Tube.

Experiment (42).—Grease the lamp-chimney and plunge it into water. Observe that the liquid is drawn away from the tube, and takes the surface, as shown at *E*, in Fig. 30.

If the tube be very small, as at *F*, Fig. 30, the cohesion of the liquid draws it down the tube, so that the level inside is much lower than on the outside. In a still narrower tube, G, the liquid is drawn still further down the tube.

The effects observed in narrow tubes are termed *capillary* effects, because they are best observed in tubes of small diameter. The word capillary means hair-like. Capillarity is a result of the attraction between the molecules of a liquid and those of a solid plunged into the liquid.

When a narrow tube is plunged into a liquid which wets it, the liquid will rise higher inside the tube than on the outside. The narrower the tube, the higher the liquid will rise.

When a narrow tube is plunged into a liquid which does not wet it, the liquid will be drawn down the tube, so that the level inside will be lower than that outside. The narrower the tube, the further the liquid will be drawn into the tube.

Experiment (43).—Capillary tubes of glass are easily made. Heat a small tube of soft glass in the flame of the Bunsen burner (Fig. 61, p. 132,) until quite soft. Keep the tube turning so as to heat all sides equally. This is most easily done by holding the tube in both hands in a horizontal position. When softened, draw the tube out with a steady and somewhat rapid motion. After a little practice, long and very fine capillary tubes can easily be obtained. With these show the experiment indicated in Fig. 29. Use ink instead of water, in order to be able the better to see the rising of the liquid. Observe that the ink rises higher in the narrower tubes. For the experiment shown in Fig. 30, mercury should be used.

90. Illustrations of Capillarity.—A lump of sugar placed in water so that only the lower part is wet, is soon wetted throughout. If we stand in water, so that only the lower parts of the clothing are wetted, we soon become wet far above the level of the water in which we are standing. Clothes sprinkled for ironing are soon damp throughout. Oil is drawn up from the body of the lamp through the wick. In all these examples, the spaces between the particles act as capillary tubes.

91. Examples of Adhesion between Liquids.— Some liquids, like milk and water, mix, because they adhere; others, like oil and water, will not mix, because they possess too little adhesion.

92. Examples of Adhesion between Solids and Gases.— The smell of tobacco-smoke adheres for some time to the clothes of one who has been smoking. Air adheres to nearly all solids.

Experiment (44).— Throw a piece of chalk or black-board crayon into water. Observe the bubbles of air that pour out of the chalk. Their adhesion to the chalk has been overcome by that of the water.

93. Examples of Adhesion between Liquids and Gases.— Nearly all gases adhere to liquids. All running water contains air.

Experiment (45).— Allow a tumbler of water to stand over night. Observe the next day that small bubbles of air cover the inner walls of the glass. The air has separated from the water.

◆

SYLLABUS.

The force of molecular attraction binds the molecules of the same or of different kinds of matter together. In cohesion, it binds together the molecules of the same kind of matter. In adhesion, it binds together the molecules of different kinds of matter.

Cohesion is the cause of tenacity. Cohesion differs in different substances. It is very weak in liquid substances. It is very strong in steel and iron. Smooth, polished surfaces of glass, or freshly-cut surfaces of lead, will cohere when pressed firmly together.

Adhesion occurs between solids, liquids, and gases. The adhesion between solids and liquids is the cause of the solution of the solid.

When a liquid wets a narrow tube which is plunged into it, the liquid mounts inside the tube higher than outside it. But if the liquid does not wet the tube, it is drawn further down the inside of the tube than it is on the outside.

The narrower the capillary tube, the higher is the liquid raised if it wets the tube, and the lower it is depressed if it does not wet it.

QUESTIONS FOR REVIEW.

Define cohesion. What is the cause of cohesion? Do all kinds of matter cohere with equal force? Can any substance, when broken or cut, be made to cohere by simply pressing the broken surfaces together? Give some examples.

Describe an experiment showing that liquids possess cohesion.

Define adhesion. What is the cause of adhesion? Does adhesion occur between all kinds of matter? Why will a clean hand be more thoroughly wetted when plunged into water than a greasy hand?

Give some examples of adhesion between different solids. Between solids and liquids.

Define capillarity. What is the cause of capillarity? What is the meaning of the word capillary?

What causes a liquid to mount higher on the inside than on the outside of a capillary tube which it wets?

Why will a handkerchief or towel become wet far above the surface of the water into which it is dipped?

Why is a liquid depressed in a capillary tube which it does not wet?

Give some illustrations of the force of capillarity.

Why will milk and water mix, and oil and water not mix?

Does air adhere to solids? Prove this by an experiment.

Does air adhere to liquids? Prove this by an experiment.

CHAPTER X.

LIQUIDS AT REST; OR, HYDROSTATICS.

94. Hydrostatics and Hydraulics.—That branch of Natural Philosophy which treats of liquids at rest is called *hydrostatics*. That branch which treats of liquids in motion is called *hydraulics*.

95. Level of Liquids in Communicating Vessels.

Experiment (46).—Pour water into a tea-pot until it is nearly full. Observe that the water stands at the same level in the spout as it does in the pot.

Experiment (47).—Incline the pot so as to lower the level of the spout. Observe that the water will run out until the water in the pot is on the same level as the mouth of the spout.

Fig. 31.—A Jet of Water.

In vessels so connected that a liquid can pass easily from one to another, the liquid will, when at rest, mount to the same level in all the vessels.

If one of the vessels is not as high as the other, and the liquid be made to nearly fill the higher vessel, as in *A*, Fig. 31, the liquid will flow out of the lower vessel, *S*, as a jet, which will rise nearly to the same level, *H*, as the water in *A*. Were it not for friction and the resistance of the air, the jet would mount quite to the level, *H*.

96. Artesian Wells.—The water rises from an artesian well for the same reason that it comes out of the opening, *S*, Fig. 31. Rain-water collected between the two curved, water-tight strata, *a*, *b*, Fig. 32, would be forced up through the opening, *o*, and escape at *c*, by reason of the pressure of the liquid at the higher level, *a a*.

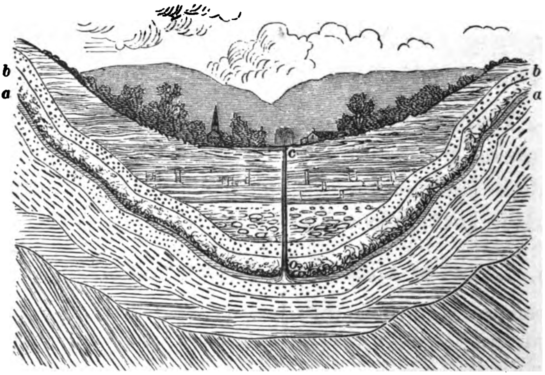


Fig. 32.—An Artesian Well.

97. Transmission of Pressure through Liquids.—The molecules of liquids move so freely over one another that, when pressure is exerted at any part of a liquid mass, it is carried or transmitted to all other parts without any sensible loss in its intensity. Moreover, since the molecules can move as easily in one direction as in another, the pressure is transmitted equally well in all directions, that is, upwards, downwards, or in any other direction.

That pressure is exerted upwards, is seen from the jet described in connection with Fig. 31. That it is exerted sideways, is seen by the escape of liquid through the bung-hole of a barrel.

98. Liquid Pressure as a Mechanical Power.—Since pressure is transmitted through liquids in all directions without sensible loss of intensity, it follows that the entire pressure received by any body is greater the greater the extent of the surface against which the liquid presses. Thus, suppose two communicating vessels, *A* and *B*, Fig. 33, filled with liquid and provided with parts, *D* and *C*, called pistons, moving freely up and down the vessels without allowing any of the water to pass above them. Then, if the surface of *D* be 1000 times greater than the surface of *C*, a weight of one pound placed on *C* will balance 1000 pounds placed on *D*; for every part of the surface of *D* equal in size to that of *C* will receive a pressure of one pound, and, as there are 1000 times as much surface in *D* as there is in *C*, *D* will receive a pressure of 1000 pounds.

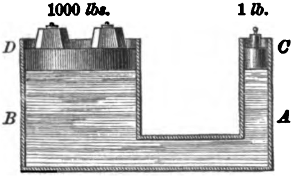


Fig. 33.—Liquid Pressure as a Mechanical Power.

99. The Hydrostatic Press.—Water pressure can be used as a mechanical power. The apparatus just described is, in fact, a simple machine, called the *hydrostatic press.* The form generally given to it is shown in Fig. 34. Water or oil is forced, by a pump from a tank, through the smaller cylinder, *A*, into the larger cylinder, *B*, where it presses against a solid piston bearing a movable platform, *C*. The upward movement of this platform exerts a great pressure against anything, such as hay, cotton, or cloth, placed between it and the fixed frame, *D*.

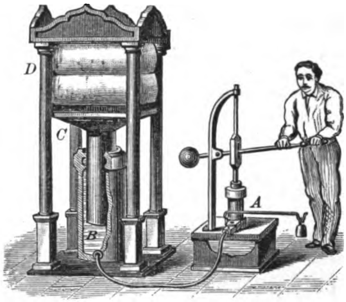


Fig. 34.—The Hydrostatic Press.

In the hydrostatic press, as in any other machine, what is gained in force is lost in time. If the one pound, in Fig. 33, raise 1000 pounds, then, if the one pound be moved down one inch, it will raise the 1000 pounds but the one-thousandth of an inch.

Problem (24).—If the areas of the small and large pistons of a hydraulic press be, respectively, 5 and 10,000 square inches, how much pressure would a force of 100 pounds at *A* produce at *C*?

Problem (25).—In the example just given, through what distance would the piston at *A* be required to move, in order to raise *B* through one foot?

100. Buoyancy of Liquids. Principle of Archimedes.

Bodies weigh less in liquids than they do in air.

A man can lift a much heavier stone when it is covered by water than when it is in the air.

A body placed in water is buoyed up, or loses a weight equal to the weight of the water it displaces; that is, it loses as much weight as the weight of a bulk of water equal to its own bulk. This fact was discovered by Archimedes, and is often called the principle of Archimedes.

The principle of Archimedes can be demonstrated experimentally by means of the parts shown in Fig. 35. A solid cylinder, *B*, of brass of such a size as to exactly fit into a hollow cylinder, *A*, is hung below *A*, and the two attached to the pan of a balance, and exactly balanced in air by weights placed in the pan, *C*.

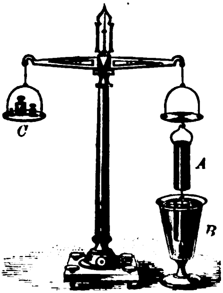


Fig. 35.
Principle of Archimedes.

If, now, the cylinder, *B*, be covered by water, it loses weight, as is seen by the pan, *C*, falling. To find how much weight *B* has lost, pour water into *A* until the equilibrium is again restored. This will occur when *A* is just full of water, which proves that *B* loses a weight equal to the weight of the bulk of water it displaces.

The cause of buoyancy is the upward pressure exerted by liquids on bodies immersed in them.

101. Floating Bodies.

Experiment (48).—Take two wine-glasses; fill one with clear water and the other with alcohol; throw some chips of box-wood or other heavy wood into each. Observe that the chips will float on the water, but will sink in the alcohol.

The chips float on the water because the weight of the water they displace is equal to their own weight, and they are therefore buoyed or held up by the water with as much force as they are pulled down by their weight. They sink in the alcohol, because the weight of the alcohol they displace is less than their own weight, and they are therefore buoyed or held up with less force than they are pulled down.

For the same reason a piece of iron will sink in water, but will float in mercury, which is a very heavy liquid.

Bodies float in liquids, if the weight of the liquid they displace is equal to their own weight.

102. Equilibrium of Floating Bodies.— The force of buoyancy acts at a point called the centre of buoyancy, situated at the centre of gravity of the displaced liquid. The force of buoyancy acts from the centre of buoyancy vertically upwards; the force of gravity acts from the centre of gravity vertically downwards. Unless the centre of buoyancy and the centre of gravity are in the same vertical line, the floating body will not be in equilibrium. Thus, the boat shown at *A*, Fig. 36, is in equilibrium, because the centres of gravity and buoyancy, *G* and *O*, are in the same vertical line; but in the position shown at *B*, it is not in equilibrium, because *G* and *O* are not in the same vertical line.

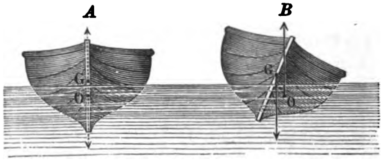


Fig. 36.—Equilibrium of Floating Bodies.

The equilibrium of floating bodies is the same as the equilibrium of a body supported on an axis around which it can freely turn. The centre of buoyancy is the point of support of the floating body. The equilibrium of floating bodies may therefore be *stable*, *unstable*, or *neutral.*

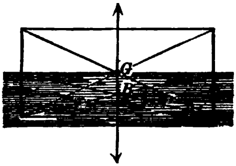


Fig. 37.
Stable Equilibrium.

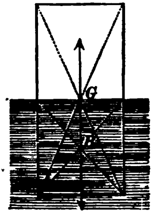


Fig. 38.
Unstable Equilibrium.

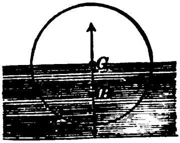


Fig. 39.
Neutral Equilibrium.

When the centre of buoyancy, *B*, is above the centre of gravity, *G*, or when the centre of gravity is as low as it can get, as in Fig. 37, the floating body is in *stable equilibrium.*

When the centre of buoyancy, *B*, is below the centre of gravity, *G*, as in Fig. 38, the floating body is in *unstable equilibrium.*

When no change in the position of a floating body can alter the relative positions of the centre of buoyancy, *B*, and the centre of gravity, *G*, as in Fig. 39, the floating body is in *neutral equilibrium.*

103. Specific Gravity.—Substances differ greatly in their weight. Some are heavy; others are light. Thus, a piece of cork of the same size as a piece of iron is much lighter than the iron. Oil is lighter than water, and when poured into water will float on top of the water. Cream is lighter than milk and rises to the surface of the milk.

In order to compare the weight of different substances, we must find the weight of equally large pieces of each. If, then, one of these substances weighs twice as much as the other, we say that its *specific gravity* is twice as great as that of the other.

By the specific gravity of a substance we mean the number of times that the substance is heavier or lighter than an equal bulk of some other substance with which the first substance is compared. We generally compare the weight of solids and liquids with water, and that of gases and vapors with air. In the following table will be found the specific gravity of a number of common substances.

SOLIDS.

Iron	=	7.78
Zinc	=	7.19
Lead	=	11.35
Copper	=	8.90
Silver	=	10.47
Gold	=	19.30
Platinum	=	22.06
Granite	=	2.75
Ice	=	.87
Cork	=	.24

LIQUIDS.

Mercury	=	13.50
Sulphuric acid	=	1.84
Milk	=	1.026
Ocean water	=	1.026
Alcohol	=	.792
Ether	=	.715

Thus, iron has a specific gravity of 7.78; that is, one cubic inch of iron weighs 7.78 times as much as a cubic inch of water. A cubic inch of gold is 19.30 times heavier than a cubic inch of water.

A cubic foot of water weighs 62.32 pounds avoirdupois; a cubic inch of water weighs .036 pound.

Problems.—(26.) What is the weight of a cubic foot of iron?
(27.) What is the weight of a cubic foot of silver?
(28.) What is the weight of a cubic foot of platinum?

(29.) How much would a cubic foot of cork weigh?

(30.) How much heavier is a cubic foot of granite than a cubic foot of ice?

(31.) How many pounds are there in 316 cubic inches of iron?

(32.) How many pounds are there in a brick of silver six inches long, three inches wide, and two inches deep?

(33.) How much heavier is a cubic foot of milk than a cubic foot of water?

(34.) How much more does a cubic foot of ocean water weigh than a cubic foot of fresh water?

(35.) What volume would ten pounds of iron occupy? One cubic inch of iron weighs $7.78 \times .036 = .28$ pound; then, if one cubic inch of iron weighs .28 pound, in ten pounds there would be $.\frac{10}{28} = 35.7$ cubic inches.

(36.) How large must a box be made in order that it may hold twenty pounds of gold?

(37.) In 1000 pounds of silver, how many cubic inches are there?

(38.) In 1000 pounds of cork, how many cubic inches are there?

(39.) What must be the capacity of a vessel that will hold 100 pounds of milk?

104. Hydrometers.—There are various methods for determining the specific gravity of bodies. For liquids, the most convenient way is by means of an instrument called a *hydrometer*. Such an instrument is seen in Fig. 40. It is made of glass, and is weighted at *C* with shot or mercury, so as to cause it to float upright when placed in any ordinary liquid. The upper part at *B* has a scale divided into equal parts. When the instrument is floated in light liquids, it sinks further than in heavy liquids. By observing on the scale the distance to which the hydrometer sinks, the specific gravity is readily ascertained.

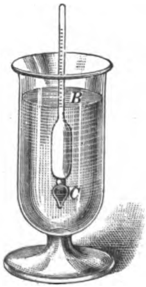


Fig. 40.
Hydrometer.

When bodies are compressed or cooled, their specific gravity is greater than when they are heated and expanded.

SYLLABUS.

Hydrostatics treats of liquids at rest. Hydraulics treats of liquids in motion.

In vessels so connected that a liquid can pass readily from one to another, the liquid will mount to the same level in all of the vessels.

In artesian wells and vertical jets of water, the liquid does not rise quite as high as the level of the liquid in the reservoir on account of friction and the resistance of the air.

Pressure is transmitted through liquids in all directions and without sensible loss of intensity.

Liquids exert pressure upwards, downwards, sideways, and in all directions.

The pressure exerted on any body is greater the greater the surface of the body against which the liquid is pressing.

In the hydrostatic press, pressure exerted against a piston moving in a small cylinder is transmitted to a piston moving in a large cylinder, which is moved forwards with great force.

Bodies immersed in liquids are buoyed up with a force equal to the weight of the liquid displaced.

The cause of buoyancy is the upward pressure exerted by liquids on bodies immersed in them.

Bodies float, if the weight of the water they displace is equal to their own weight.

Buoyancy acts at a point called the centre of buoyancy. If the centre of gravity is in the same vertical line as the centre of buoyancy, the floating body will be in equilibrium.

By the specific gravity of a substance is meant the number of times that the substance is heavier or lighter than an equal weight of water or other substance with which the weight of the first is compared.

A very convenient way for determining the specific gravity of liquids is by means of a hydrometer.

QUESTIONS FOR REVIEW.

Define hydrostatics. Define hydraulics.

Describe any experiment showing that liquids in communicating vessels will, when at rest, stand at the same level in all the vessels.

Explain the cause of vertical jets of water.

What causes the water to come out of the opening of an artesian well?

State the law for the transmission of pressure in liquids.

Explain how pressure exerted on a liquid mass may be employed as a mechanical power.

Describe the hydrostatic press.

State the principle of Archimedes. How may the correctness of this principle be demonstrated experimentally?

When will bodies float in water?

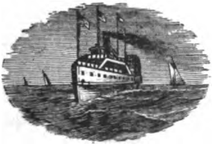
When will floating bodies be in equilibrium?

Define centre of buoyancy.

When will a floating body be in stable equilibrium? When will it be in unstable equilibrium? When will it be in neutral equilibrium?

Define specific gravity. With what is the specific gravity of solids and liquids generally compared? With what is the specific gravity of gases or vapors generally compared?

Describe the hydrometer.



CHAPTER XI.

LIQUIDS IN MOTION; OR, HYDRAULICS.

105. Hydraulics treats of liquids in motion. It studies the flow of liquids, the machines for moving liquids, and those to be moved by them.

106. Cause of Flow of Liquids.—Since liquids press in all directions, a vessel filled with liquid has a pressure against its sides as well as against its base. If, therefore, an opening be made in the side of a vessel, the liquid will flow out. It flows out of the opening on account of the pressure caused by the weight of the water above the opening. Therefore the further the opening be below the level of the water, the faster the liquid will escape.

Experiment (49).—Pierce three small holes in the side of an empty tomato-can, one near the top, one in the middle, and one near the bottom. Stop these holes with little wooden plugs, such, for example, as match-stems. Fill the can with water; then removing the three plugs, observe that the water escapes most rapidly from the lowest hole and least rapidly from the upper hole. To prove this, hold a wine-glass for half a minute so as to catch the water escaping from the upper hole. Observe the amount in the glass. Now, emptying the glass, hold it for the same time so as to catch the water escaping from the middle hole, and observe the amount as before.

Do the same with the lower hole. Most will have escaped from the lower hole and least from the upper; therefore, the escape must have been most rapid from the lower hole and least rapid from the upper hole. Since, during these experiments, the level of the liquid in the can will gradually lower, have some one keep the can full by gradually adding water.

107. Depth of Water over Orifice, or Head.—The water escapes most rapidly from the lowest hole, above which there is the greatest depth of water, and where there is the greatest pressure to force it out. This depth of water, or the distance in a vertical line from the surface to the middle of the hole, is called the *head.* If the head is four times greater in one case than in another, the velocity of escape of the liquid will be twice as great, $\sqrt{4} = 2$. If the head is increased nine times, the velocity of the flow will be three times as great, $\sqrt{9} = 3$.

The velocity of escape of a liquid from an opening in a vessel is as the square root of the head.

Problem (40).—How much faster will water escape from an opening in the side of a vessel three feet below the surface than from an opening one inch below the surface?

Problem (41).—How much must the head under which a liquid is escaping from an orifice in a vessel be increased in order that the velocity of escape shall be increased five times?

In all large cities or towns water is supplied to the houses through long pipes laid in the streets, and connected with a large reservoir situated on some hill or other elevation. The level of the water in this reservoir being at a greater height than the openings at the faucets in the houses, the water runs out whenever these faucets are opened.

Water runs less rapidly from the faucets near the top of a house than it does from those on the lower floors, because in the latter case the head, or pressure, causing it to escape is less.

When liquid flows through long pipes, friction causes it to escape from any opening in the pipes with rather less velocity than it would escape from an opening in the side of a vessel under the pressure of the same head.

108. The Flow of Rivers.—Rivers flow because the level of the water at their sources is higher than the level at their mouths. The greater the inclination of a river the greater its velocity of flow. Therefore the current is swifter in the mountainous or hilly part of the river, near the source, than it is in the low, flat country near the mouth.

The velocity of a river also increases with the quantity of water in the river; therefore, during floods or inundations, the river flows more rapidly than it does during droughts. The velocity at the surface is rather less than at some little distance below the surface, owing to the resistance of the air. The surface velocity in most rivers varies from two to four miles an hour. During floods, it is much greater.

109. Water-Wheels.— Since matter never moves unless energy acts on it, there is little difficulty in seeing that the moving water of a river represents considerable energy of motion. It can be caused to give this motion to water-wheels, which in their turn set in motion various machinery.

There are different forms of water-wheels. We will describe those in common use.

110. The Undershot Water-Wheel.— The undershot water-wheel is represented in Fig. 41. The water strikes near the bottom of the wheel against flat boards, *B*, *B*, *B*, placed at equal distances apart on the rim of the wheel, as shown. The wheel is driven around the axis, *A*, by the force of the current driving the water against the boards. A gate, *G*, which can be raised or lowered, is used to regulate the quantity of water which escapes from the reservoir, *R*.

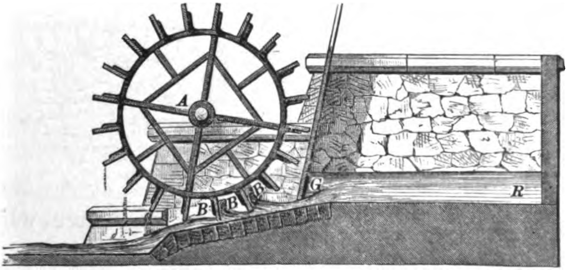


Fig. 41.—The Undershot Water-Wheel.

111. The Overshot Water-Wheel.— The overshot water-wheel is represented in Fig. 42. The water is received near the top of the wheel by curved buckets, *B*, *B*, *B*, shaped so as to retain the water until it reaches the lowest point. The wheel is turned around the axis, *A*, by the force of the current and the weight of the water in the buckets on one side of the wheel. It will be seen from the figure that no water can remain in the buckets on the right of the wheel.

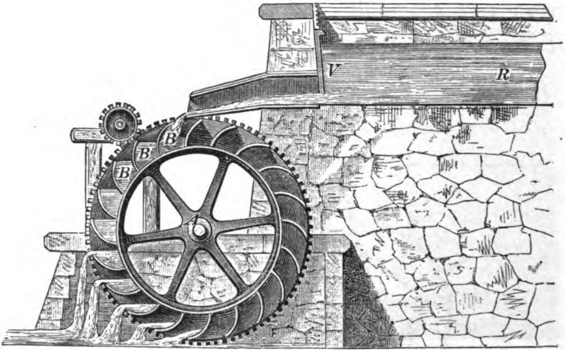


Fig. 42.—The Overshot Water-Wheel.

A gate, *V*, regulates the quantity of water which escapes from the reservoir, *R*.

112. The Breast Water-Wheel.—The breast water-wheel is represented in Fig. 43. The water is received on the wheel near the level of the axis, *A*, by buckets, *B*, *B*, *B*, shaped so as to hold the water until they reach the lowest point. This is done by causing the ends of the buckets to move near the

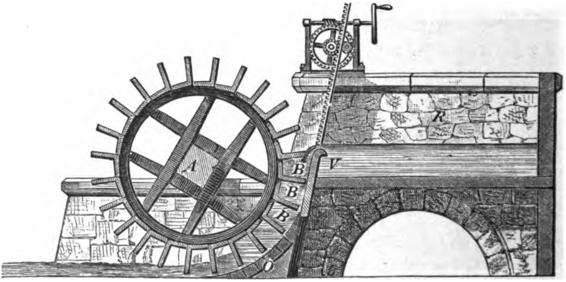


Fig. 43.—The Breast Water-Wheel.

curved way, *O*, down which the water runs. The buckets are placed perpendicularly to the rim of the wheel, as shown. As in the other forms of wheel, the escape of the water from the reservoir, *R*, is regulated by the gate, *V*. In the breast-wheel, the wheel is moved around an axis at *A* by the weight of the water and the force of the stream.

113. The Cause of Waves.— Waves are caused by the action of the wind. The wind blowing on the water sets it in motion. The stronger the force of the wind the higher the waves. With the same force of wind, the deeper the water the higher the waves. High waves move forwards more rapidly than low waves The water, however, does not move forwards: objects floating on the water merely rise and fall.

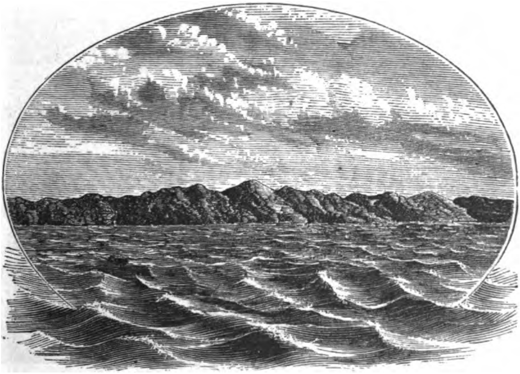


Fig. 44.—Waves.

* * *

SYLLABUS.

Hydraulics treats of liquids in motion. It studies the flow of liquids, and the machines for moving liquids or to be moved by them.

When an opening is made in the side of a vessel filled with water, the water will flow out on account of the pressure produced against the opening by the weight of the water above it.

The distance measured in a vertical line from the middle of the opening to the surface of the liquid is called the head. The velocity of escape is as the square root of the head. If the head be increased four times, the velocity of escape will be increased the square root of four, or twice.

Water runs out of the faucets connected to water-pipes because of the higher level of the water in the reservoir with which the pipes are connected.

Rivers flow because the level of the water at their sources is higher than the level near their mouths.

The steeper the inclination of a river, the greater the velocity of its current. The greater the quantity of water in a river, the greater the velocity.

We can transfer the energy of motion of a stream, to machinery, by means of water-wheels.

In the undershot-wheel, the water is received near the lower part of the wheel; in the overshot-wheel, it is received near the top; in the breast-wheel, it is received near the level of the axis.

Waves are caused by the action of the wind on the water.

QUESTIONS FOR REVIEW.

Define hydraulics.

What is the cause of the escape of a liquid from an opening made in the side of a containing vessel?

In what part of a vessel must the opening be made in order that the liquid should run out with the greatest velocity? Why is this the case?

How can it be proved that a liquid will run out of holes near the bottom of a vessel faster than out of holes near the top?

Give the law for the increase of the velocity of escape of a liquid with the increase of the head. Define head.

How much must the head be increased in order to double the velocity of escape? How much in order to treble it?

Why does the water escape from the water-faucets in the lower parts of a house more rapidly than from those in the upper parts?

What is the cause of the flow of water in rivers? Why is the current swifter near the source of a river than near the mouth?

Why does the velocity of a river increase during a flood or inundation?

How can the energy of motion of a river be transferred to machinery?

Describe the undershot water-wheel. Where is the water received in this wheel? How are the buckets shaped? How does the water give motion to this wheel?

Describe the overshot water-wheel. How are the buckets shaped? How long do they retain the water? How does the water give motion to this wheel?

Describe the breast water-wheel. How long is the water retained by the buckets? How does the water give motion to this wheel?

What is the cause of waves?

CHAPTER XII.

GASES AT REST OR IN MOTION; OR, PNEUMATICS.

114. Tendency of Gases to Expand.—Gases are substances in which the molecules are driven apart with greater force than they are drawn together. The molecules are constantly endeavoring to get further and further apart; that is, the gas has always a tendency to expand. In most cases, it is prevented from expanding indefinitely by the action of some outer force. Thus, the air around us is prevented from expanding by the weight of the air above it. Were this weight removed, the air would at once expand, as may be proved by partly filling a small bladder with air and then placing it under a glass vessel, *R*, Fig. 45, placed on the plate, *P*, of an air-pump. As air is removed from *R*, the air in the bladder, relieved from the pressure due to the weight of the air, at once expands and fills the bladder; but if air is again allowed to enter *R*,

Fig. 45.—Expansion of Air in Vacuous Space.

the gas in the bladder is compressed into its former bulk.

115. Diffusion of Gases.—The atmosphere, which is, in fact, a vast ocean of air surrounding the earth, is composed mainly of a mixture of two gases, called nitrogen and oxygen. Of these, the oxygen is somewhat heavier than the nitrogen. There is also a small quantity of another gas called carbonic acid, which is much heavier than either the oxygen or the nitrogen.

These substances do not, however, settle in layers according to their weight, as most liquids will do, but, by reason of a peculiar property of gases, called *diffusion*, are equally mixed throughout the air, so that we would find the same proportion of the heavy carbonic acid gas in the air around the summit of a high mountain as we would in the valley at its base. The diffusion of gases is due to the attraction between their molecules.

116. Properties Common to Gases and Liquids.—The following properties are common to both gases and liquids; viz.,

1st. *Gases transmit pressure equally in all directions. They press upwards, downwards, and sideways.*

2d. *Bodies weighed in air are buoyed up, or lose as much weight as the weight of the air they displace.*

It is owing to this loss of weight that balloons rise through the air, since the buoyancy, or upward pressure of the air on them, is greater than their weight. Balloons rise through the air for the same reason that a cork or piece of wood plunged beneath water rises to the surface.

117. Atmospheric Pressure.—Since we live at the bottom of the atmosphere, we must, like everything else at the earth's surface, sustain a pressure arising from the weight of the air above us. Gases, however, like liquids, transmit pressure equally in all directions, and these opposite pressures so neutralize each other that we do not feel the pressure which the air exerts on us. If, however, the pressure should be removed from one side, the pressure on the opposite side would at once be felt. The air presses so equally on all sides of bodies, that it was long before the atmospheric pressure was discovered. The discovery was made by Torricelli.

118. The Barometer. Torricelli's Experiment.—Torricelli was an Italian. He discovered that the air presses on things on the earth by the following experiment: he took a glass tube about thirty-three inches long, closed at one end, and, filling it with mercury, placed his thumb over the open end, as shown in Fig. 46, at *A*. He then inverted the tube, and, dipping its open end beneath a cup of mercury, he removed his thumb, holding the tube in the position shown at *B*. The mercury did not all run out of the tube; a column thirty inches high was kept in the tube by the pressure of the air on the surface of the mercury in the cup.

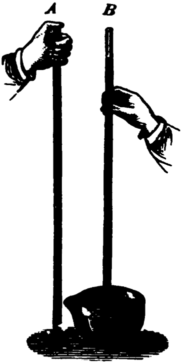


Fig. 46.
The Barometer.

It is the downward pressure or weight of the air that forces the mercury up into the tube. The column of air, whose weight balances the column of mercury, is of the same thickness as the column of mercury, but reaches from the level of the mercury in the cup to the top of the atmosphere.

At the level of the sea, the pressure of the air holds up a column of mercury whose height extends thirty inches above the level of mercury in the cup. If the area of the open end of the tube be one square inch, the column of mercury in the tube will weigh fifteen pounds; but these fifteen pounds are sustained by a column of air whose base is one square inch.

Therefore, at the level of the sea, the atmosphere presses with a weight of fifteen pounds on every square inch of surface.

Problem (42).—The area of the earth is 197,000,000 square miles. What is the entire weight of the atmosphere?

Problem (43).—What pressure does the air at the level of the sea exert on a surface of six square feet?

Torricelli's tube forms an instrument called the *barometer*, and enables us to know when changes occur in the pressure of the air; for if the pressure of the air becomes greater at any time, it causes the mercury to rise in the tube; if it becomes less, it allows the mercury to fall in the tube.

119. Uses of the Barometer.—Changes in the weather are almost always attended by changes in the pressure of the air. *By noticing the risings or fallings of the barometer, we can, especially at sea, often foretell coming changes in the weather.*

If we take a barometer to the top of a mountain, the mercury will fall in the tube, because there is less weight of air above the mercury in the cup. The higher the mountain, the more will the mercury fall. *Hence, the barometer may be used to determine the height of mountains or other elevations.*

120. Experiments in Atmospheric Pressure.

Fig. 47.—An Experiment in Atmospheric Pressure.

Experiment (50).—Fill a smooth-edged tumbler with water, and, placing a piece of writing-paper over the top, press the palm of the hand against the paper, and slowly invert the tumbler. The hand may now be removed, and the tumbler held in the position shown in Fig. 47. Observe that the upward pressure of the air against the paper prevents the water from running out of the tumbler.

Experiment (51).—Place the open end of a hollow key to the mouth, and, sucking out the air, press it quickly against the lip. Observe that it is held there with considerable force by the pressure of the air.

Experiment (52).— With a nail, pierce a small hole in the end of an empty tomato can, from the top of which the small round piece of tin only has been removed, leaving an opening about two inches in diameter. Tie a piece of mosquito netting firmly around this end of the can, stretching it smoothly over the top. Place a piece of stiff paper over the open end, and, keeping a finger over the hole in the bottom, invert as in the previous experiment. Now, holding as shown in Fig. 48, with its end perfectly horizontal, slowly slide the paper away from the can. Observe that, although the opening in the can is only covered by the netting, the water does not escape, being still kept in by the pressure of the air. If the air could force its way into the can, the water would run out. This it cannot do, because the air cannot push its way through the water covering the meshes of the netting. This shows that the water adheres to the netting with considerable force, and also that the molecules of water, which cover the opening, cohere with considerable force.

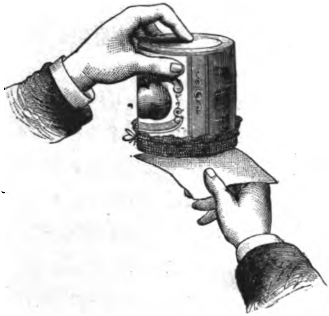


Fig. 48.—An Experiment in Atmospheric Pressure.

Fig. 49.—An Experiment in Atmospheric Pressure.

Experiment (53).—Now raise the finger as shown in Fig. 49, uncovering the nail-hole. The air can now freely enter the can. Observe that the water escapes through the netting. Again stop the hole with the finger, and observe that the flow of water ceases. In these experiments the can must be held very steadily.

In the case of liquids escaping from openings in the side of a containing vessel, we must therefore consider the pressure exerted by the atmosphere tending to keep the liquid in, since this pressure, as we have just seen, may be greater than that arising from the weight of the liquid above the opening.

121. Effect of Pressure on the Volume and Specific Gravity of Air.— *As the pressure on a gas is increased, its volume is decreased, and its specific gravity or density increased.* If the pressure be made twice as great, the volume is diminished to one part of what it was, but the density is doubled.

Since the lower layers of the atmosphere have to sustain the weight of the air above them, the lower layers must be denser than the upper layers.

122. Machines Depending for their Action on the Pressure of the Atmosphere.

The Siphon.—A siphon consists of a tube bent as shown in Fig. 50. If the shorter end of such a tube be placed beneath a water surface, *m*, and the air sucked out of the tube by the mouth at the end, *b*, the pressure of the air will cause the water to rise through the height, *m n*, and escape in a steady stream from the end, *b*, until the level of water in the shorter arm falls below the open end of the tube. When the pressure of the air forces the water up into the tube, so that the tube is completely filled, the greater weight of the water in the long arm of the siphon, than in the short arm, causes the liquid to escape from the long arm. Hence, the greater the vertical distance, *a b*, between the level, *m a*, and the opening at the larger end, the more rapidly the water will escape.

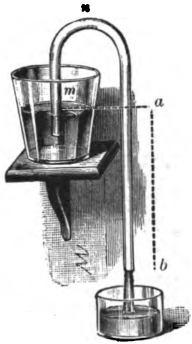


Fig. 50.—The Siphon.

123. The Suction-Pump for Water.—Water is forced up from a well into the body of a pump by means of the pressure of the air. The common suction-pump is shown in Fig. 51. A water-tight piston moves up and down in the cylindrical body or barrel of the pump. A tube or pipe extends from the bottom of the pump-barrel to the water in the well. A valve, *a*, opening upwards is placed over the top of this pipe, in the bottom of the barrel, as shown. Valves, *b b*, also opening upwards are placed in the piston. By the movements of the piston, the air is sucked out of the pipe dipping down into the well, when the pressure of the air on the water in the well forces the water up into the body of the pump through the valve, *a*. This occurs when the piston is moving upwards. On the piston moving downwards, the valve, *a*, is closed, and the valves, *b b*, in the piston opened, so that the water now passes above the piston, and on the next up-stroke is discharged at the opening, *D*. The drawing shows the position the valves have when the piston is moving upwards.

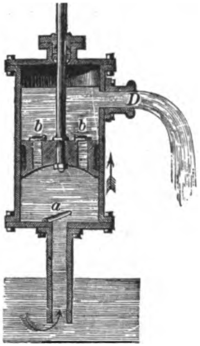


Fig. 51.
The Suction-Pump.

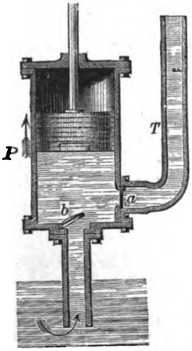


Fig. 52.
The Force-Pump.

124. The Force-Pump for Water.— In the force-pump there is no valve in the piston. The valve, *b*, Fig. 52, occupies a position similar to that of *a* in Fig. 51. A pipe, *T*, enters the side of the cylinder near the bottom. A valve, *a*, opening into the pipe, is placed where the pipe enters the cylinder. After the pressure of the air has forced the water out of the well into the barrel of the pump, on the down-stroke of the piston, the valve, *b*, is closed, and the water forced through *a* into the pipe, *T*. The drawing shows the position of the valves when the piston is moving upwards.

A column of water thirty-four feet high exerts a pressure equal to that of the atmosphere. Therefore in none of the apparatus just described can water be raised to a greater height than thirty-four feet. In practice, pumps seldom raise water higher than twenty-eight feet from the level of the well to that of the lower valve.

SYLLABUS.

In gases, the force acting on the molecules tending to separate them is stronger than the force which draws them together.

Gases are constantly endeavoring to expand. If the pressure on a gas is decreased, it at once expands.

The gaseous ingredients of the atmosphere, though of different densities, are evenly diffused or mixed throughout.

Gases transmit pressure equally well in all directions.

Bodies weighed in air are buoyed up with a force equal to the weight of the air they displace.

Balloons rise through the air because their weight is less than the weight of the air they displace.

The air above us exerts a pressure on everything beneath it. We do not feel this pressure, because it is evenly exerted in all directions. If the pressure on any side of a body be removed, the pressure on the opposite side is at once felt.

The pressure of the atmosphere, at the level of the sea, is equal to fifteen pounds to the square inch.

The atmospheric pressure will cause a column of mercury to rise in the barometer to the height of thirty inches above the level of the mercury in the cup.

The barometer enables us to know when changes occur in the pressure of the air. It may also be used to determine coming changes in the weather, and to ascertain the height of mountains or other elevations.

As the pressure on a gas is increased, the volume of the gas is decreased and its density is increased.

The lower layers of the atmosphere are denser than the upper layers, because they have to bear the weight of the upper layers.

The siphon, and the suction- and force-pumps for water, depend for their action on the pressure of the air.

A column of water thirty-four feet high has the same weight as an equally thick column of air reaching from the sea-level to the top of the atmosphere.

QUESTIONS FOR REVIEW.

Why should all gases have a tendency to expand? Describe any experiment which shows this tendency.

What is meant by the diffusion of gases? What is the cause of diffusion?

Name some of the properties common to both gases and liquids.

What causes a balloon to rise through the air?

What is the cause of atmospheric pressure? Who first discovered the pressure of the air?

Describe the construction of the barometer. For what is the barometer employed?

Describe any experiments by means of which the pressure of the air can be shown. Which of these proves that water possesses considerable adhesion and cohesion?

What effect on the volume of a gas is produced by an increase of pressure? What effect on the density of a gas is produced by an increase of pressure?

Describe the siphon. What forces the water up into the short arm of a siphon? Why does the water run out from the long arm?

Describe the suction-pump for water. How many valves are there in this pump? How do they open? What positions have the valves when the piston is moving upwards? When it is moving downwards?

Describe the force-pump for water. How many valves are there in this pump? Where are they situated? How do they open? What positions have the valves when the piston is moving upwards? When it is moving downwards?

CHAPTER XIII.

SOUND.

125. Wave-Motion.—When a stone is thrown into water, we see a number of circular waves formed around the place where the stone strikes the surface. Where the stone strikes the water, a depression is made and the water is piled up around it. The water in the depression, however, quickly rises, and even mounts above its ordinary level. The motion is soon communicated to the rest of the water, and around the point where the stone entered the surface a series of circular waves is formed, in which the water is alternately above and below its level when at rest.

Experiment (54).—Tie a ball to a string formed of elastic gum, as in the common return-ball. Holding the end of the string in the hand, allow the ball to drop. Observe that it falls for a certain distance, stretching the gum, when the elasticity of the gum causes it to rise until its weight again causes it to fall. Observe, too, that these motions continue for some little time, the ball alternately falling and rising in a nearly vertical direction.

When the ball falls, the string lengthens; when the ball rises, the string shortens. It is the elasticity pro-

duced by these lengthenings and shortenings, that causes the ball to move down and up.

If any part of the air is suddenly disturbed; for example, if it be compressed, it will, on expanding, move to and fro, like the string holding the return-ball, and the compressed part will become alternately less dense, and more dense, than the surrounding air. But these motions are not confined to the air first acted on; they spread in all directions around the point where the air was disturbed and cause spherical waves, in which the air is alternately more and less dense than the surrounding air.

126. The Cause of Sound.—When a bell is struck so as to sound, its sides shake to and fro. These shakings disturb the air around the bell, and cause in it spherical waves, which move out from the bell in all directions. If these waves enter the ear, we hear the sound of the bell. In Fig. 53, the manner in which the sound-waves reach the ear of a listener is shown. The shaded portions represent the parts where the air

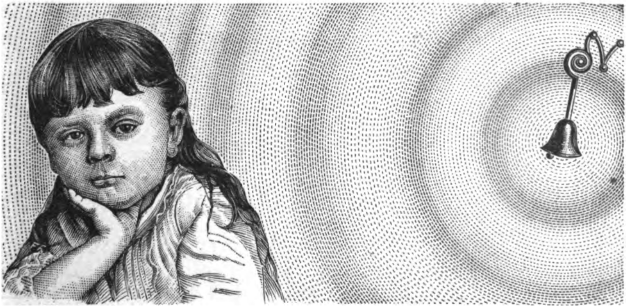


Fig. 53.—The Transmission of Sound.

is more dense, and the lighter portions, the parts where it is less dense, than the surrounding air.

Sound is caused by the vibrations or shakings of the sounding body, and is carried to the ear by waves.

127. Sound-Waves Spread in all Directions in the Air.—Since gases transmit pressure equally well in all directions, it follows that sound-waves should spread equally in all directions. For this reason, a person, at a window near the top of a house, can hear a noise in the street as well as if he were on the pavement, at the same distance from whatever made the noise. The waves, therefore, must spread upwards as well as sideways.

128. All Bodies Shake to and fro While Causing Sound.—If sound is caused by shakings of the sounding body, it, of course, follows that all bodies while causing sound must be shaking to and fro.

If a bell is struck so as to sound, we can, by lightly touching its sides, feel that they are shaking to and fro. If it is sounding very loudly, we can even see these shakings. If we touch the sides of the bell so as to stop the shakings, the sound at once ceases.

Experiment (55).—Partly fill a glass goblet with water, and sound it by rubbing the moistened fingers or a violin-bow over its edge. Observe that, as long as the sound can be heard, waves can be seen on the surface of the water. These waves are caused by the shakings to and fro of the sides of the goblet.

When the keys of a piano are struck, little wooden hammers are caused to strike wires, stretched tightly over a strong frame. The sound is caused by the shakings to and fro of these wires. If the hand be placed on any wire while it is sounding, in such a way as to stop its motion, its sound at once ceases.

129. Sound not Carried across a Vacuum.— Since sound is carried from the sounding body to the ear by means of waves, it follows that sound cannot cross an empty space where there is nothing to be set into waves. If, for example, a bell be hung in a hollow globe, *B*, as shown in Fig. 54, and the air be all removed from the globe, no sound will be heard when the bell is struck, since there is nothing to carry the shakings of the bell across the empty space between it and the walls of the glass globe. A faint sound may sometimes be heard; this is caused by the waves that are carried through the string by which the bell is supported.

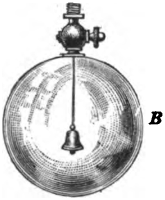


Fig. 54.— Bell in Empty Globe.

130. Sound-Waves Transmitted by all Elastic Substances.— When sound-waves are caused in any part of the air, they are transmitted through the air, because it is elastic.

Any elastic substance will transmit sound-waves; because in any elastic substance, if vibrations or shakings to and fro are caused at any part, they will spread in all directions through the substance.

Strings, wires, rods of wood or metal, liquids and gases, are elastic; therefore, sound-waves may be transmitted through them.

Experiment (56).— Remove the bottoms of two small tin cans; moisten a piece of bladder and stretch it tightly over the end of each, securing it to the can by tying a string around it. When the bladder is dry, it should be found to be tightly stretched across the end of the can like a drum-head. Now pierce a hole in the middle of each end of the bladder with a large darning-needle; get a piece of string, fifteen or twenty feet long, and run one end through each of these holes from the outside of the can to the inside, and tie a piece of match-stem to each end of the string to prevent it being pulled out. If now, while the string is stretched rather tightly, a person places his ear at the open end of one of the cans, he can distinctly hear all that is said by a person whispering into the open end of the other can, as shown in Fig. 55. This instrument is called a string-telephone. The vibrations causing the sound are carried from the speaker to the listener through the string.


Fig. 55.—The String-Telephone.

Experiment (57).— Place the ear against the end of a long wooden bench. Observe that very faint sounds made at the far end, such as the scratching of a pin, can be distinctly heard.

Experiment (58).— Ring a bell under water. Observe that the sound, though different from that heard in the air, is nevertheless audible.

131. Time Required for Sound-Waves to Move from Place to Place.—We see a distant man strike a blow with a hammer some time before we can hear the sound. We see the lightning which causes the thunder some time before we hear the thunder.

It is evident, therefore, that time is required for sound-waves to wave from place to place.

In air at the temperature of melting ice, that is at 32°, sound-waves move through a distance of 1090 feet in every second. In warmer air, the waves move rather more rapidly, increasing about $1\frac{1}{10}$ feet for every degree of temperature above 32°.

Problems.—(44.) In air at the temperature of 32°, how long will it take sound-waves to move through a distance of one mile?

(45.) Through what distance in this air will sound-waves move in four seconds?

(46.) What is the velocity of sound per second in air at 60°? $60° - 32° = 28°$. $28 \times 1\frac{1}{10}$ feet $= 30.8$ feet. $1090 + 30.8 = 1120.8$ feet. *Ans.* 1120.8 feet per second.

(47.) How far will sound-waves move in six seconds through air at 70°?

Sound-waves move about four and a half times more rapidly through water than through air.

Sound-waves move more rapidly through solids than they do through liquids. Thus, they move about ten and a half times more rapidly through cast-iron than they do through air.

132. Reflection of Sound. Echoes.—When a ball is thrown obliquely against a wall, it flies off or is reflected from it. Sound-waves move in all directions in straight lines, but when any suitable object, like a wall, is in the way of the waves, they are reflected from it like the ball. This change in the direction of the waves is called the *reflection of sound-waves.*

When the object causing the reflection is sufficiently distant, if we stand in front of it and cry out in a loud voice, we will, after the sound has died away, hear a second sound like the first, but fainter. This is caused by the sound-waves, which have been reflected by the distant object, coming back to us and entering our ears.

133. Effect of Distance on Sound.— While walking towards a distant bell which is sounding, we notice that the sound grows louder and louder as we near the bell. It can be shown that the loudness, or intensity of any sound, decreases as the square of the distance from the sounding body. Thus, if, at a distance of ten feet from the bell, we hear the sound with a certain *loudness* or *intensity*, at twenty feet, or twice as far, the intensity would be but one-fourth as great, that is, as $(\frac{1}{2})^2 = \frac{1}{4}$.

If, instead of allowing the sound-waves to spread in all directions, we limit their spreading to but one direction, as through the string or wire of a telephone, the intensity or loudness does not decrease so rapidly.

Experiment (59).—Speak in a low voice into one of the open ends of a long rubber water-hose. Observe that one listening at the other end can distinctly hear all that is said. Here the sound-waves only spread in one direction; viz., through the air in the hose.

134. The Peculiarities of Musical Sounds.— Observation will convince us that all sounds are not the same. They differ from one another in a variety of ways. These differences, however, may all be traced to three peculiarities; viz., *the intensity*, *the pitch*, and *the quality*.

135. The Intensity or Loudness of Sound.— This, as we have seen, is affected by our distance from the sounding body. The same body, however, can be caused to give faint or feeble sounds. For example, if a bell be feebly struck, it will emit a fainter sound than if it be struck forcibly. These differences are caused by the fact that when the bell is struck forcibly, the waves it makes in the air around it have greater differences in their density than those caused when the bell is struck feebly.

The speaking-trumpet is used to allow the voice to be heard at a distance. It does this by throwing the sound nearly in one direction only. It is conical in shape, and has a trumpet-shaped end. The small end is held to the mouth of the person speaking.

Experiment (60).—Roll a piece of pasteboard into a cone; place the mouth at the small end, and talk or sing into it. The voice will be greatly strengthened. Point the cone directly at a person standing in the far end of a room, and whisper. He will be able to hear distinctly all that is said, while those on either side of the instrument, but nearer it, are unable to hear.

The ear-trumpet is used to aid deaf persons in hearing. It acts by concentrating the voice on the listener's ear. Its shape is similar to that of the speaking-trumpet, only the small end is placed in the ear, and the person talks into the large end.

Experiment (61).—Place the small end of the paper cone used in the preceding experiment in a person's ear, and whisper into the large end, and, if no defect of hearing exists, he will hear distinctly. Go to the far end of the room and again whisper, though somewhat louder, and he will still hear what is said.

136. The Tone or Pitch of Sounds.—By the *tone* or *pitch* of a sound is meant the peculiarity that enables us to distinguish between sounds that are high or low.

The more rapidly the sounding body moves to and fro, the greater will be the number of waves it makes in the air in a given time, and the higher or shriller will be the pitch of its sound.

In a piano, the short, thin wires shake more rapidly than the long, thick wires, and, therefore, give higher, shriller notes.

137. The Quality of Sounds.—If we sound the same note equally loud on a flute, and on a violin or piano, we can distinguish the sounds one from another, although their loudness and pitch are the same. They differ in their *quality*. So, too, the voices of two people, speaking equally loud and in the same tone, differ.

These differences in the quality of tones are due to the fact that sounds are seldom pure. In nearly every case when a sound of a given tone is made, there accompanies it a number of other sounds of different pitch, but of such feeble intensity that we cannot hear them unless we listen attentively. These additional tones are different in different sounds, and are the cause of differences of quality.

SYLLABUS.

When a stone is thrown into water, circular waves are formed around the spot where the stone strikes. In these waves the water is alternately elevated and depressed, above and below its level when at rest.

When a bell is sounded in the air, spherical waves are formed, which move out from the bell in all directions. In these waves the air is alternately more and less dense than the surrounding air.

The sound of a bell is caused by the vibrations, or shakings to and fro, of the walls of the bell.

Sound is carried from the sounding body to our ears by means of spherical waves in the air.

Sound-waves spread equally well in all directions.

All bodies shake to and fro while producing sound.

Sound is not carried across an empty space. Some kind of matter must be present to carry the shakings from the sounding body to the ear.

All elastic substances transmit sound. Wires, strings, rods of wood or metal, liquids, and gases are elastic; they, therefore, transmit sound.

Sound-waves require time to move from place to place. They move faster in warm than in cold air. They move faster in liquids than in gases, and faster in solids than in liquids.

Echoes are caused by sound-waves, the direction of which has been changed by reflection from some distant object, and which have reached the ear after the sound, whose echo is heard, has ceased.

The intensity or loudness of a sound decreases with the distance from the sounding body.

Sounds produced by waves in which the air is alternately very dense and very rare, are louder than those produced by waves in which these differences of density are not so great.

Sounds produced by bodies that shake to and fro very rapidly are shriller and higher than those produced by bodies that do not shake to and fro so rapidly.

The differences in the quality of tones are caused by the differences in the feeble tones that accompany nearly all tones.

QUESTIONS FOR REVIEW.

Describe the nature of the waves that are caused in water by a stone falling into it.

Describe the nature of the waves that are caused in air by the ringing of a bell. Are these waves similar in any respect to the motions to and fro of the string of a return-ball?

What is the cause of sound? How are sounds carried or transmitted to the ear?

Prove that sound-waves spread equally well in all directions.

Why must all bodies that cause sound shake to and fro? Describe any experiment which proves that a body is shaking to and fro while sounding. Why cannot sound be carried across an empty space?

Will any elastic substance transmit sound? Describe experiments which show that sound can be carried from a sounding body to the ear through strings, boards, and liquids.

State some facts which prove that time is required for sound-waves to move from one place to another.

Through what distance will sound-waves move in air at the temperature of 32° in one second of time? What effect has an increase of temperature on the distance through which the waves will travel in a given time?

What is meant by the reflection of sound? Explain the cause of echoes.

Explain the effect produced on the loudness or intensity of sound by the distance from the sounding body.

Why are some sounds loud and others feeble? Describe the construction and use of the speaking-trumpet.

Describe the construction and use of the ear-trumpet.

Describe experiments showing the use of both the speaking-trumpet and the ear-trumpet.

Why are some sounds shrill or high and others low or grave?

Which strings on a piano give the shrill notes? Which give the low notes? Explain the reason for this.

What is meant by the quality of a tone? By what are differences in the quality of tones caused?

Give some examples of differences in the quality of different sounds.

Name the characteristics of musical sounds.

CHAPTER XIV.

THE NATURE OF HEAT. EXPANSION.

138. The Cause of Heat.—The molecules of matter are never at rest; they are constantly moving towards and from one another. *Heat is caused by these motions.* The cause of heat is, therefore, similar to the cause of sound, but the nature of the motion is different. In causing sound, the whole mass of the body moves to and fro, while in causing heat, only the molecules of the body move to and fro.

139. The Luminiferous Ether.—We have seen that the vibrations of a sounding body are carried to the ear by means of waves, and that these waves are transmitted through all elastic substances. A sounding bell, therefore, hung in the vessel, *B*, Fig. 54, cannot be heard if the vessel be empty, since there is nothing then in it that can carry the vibrations to the walls of *B*, and thence to the outer air. But if, instead of the bell, we hang a hot body *in what seems to us to be an empty space*, we find that the heat readily passes through this space. For this, and for other reasons, we believe that all space, even though it seems to be empty, is filled with something which is set into wave-motions by the shakings to and fro of the molecules of hot bodies. This something, which fills all space, is called the *luminiferous ether*, *and it is by means of waves in it that heat is transmitted or carried from place to place.* It is called the luminiferous ether, because it also transmits light by wave-motions in it.

The luminiferous ether is highly elastic, and is so light that its weight cannot be detected.

140. Hot Bodies Give off their Heat by Means of Waves.—Hot bodies give their heat to bodies around them by means of waves that they cause in the luminiferous ether. The ether can readily pass through the spaces between the molecules, so that the molecules are surrounded by it; and when they move to and fro, they cause, in the ether around them, a wave-motion, which spreads rapidly in all directions. When these ether-waves strike against other bodies, if they set the molecules of these bodies into vibration, so as to cause them to move to and fro, the other bodies become heated.

141. Heat a Form of Energy.—We have seen that force, or energy, must act on matter in order to set it into visible motion. It is none the less true that force or energy must be imparted to matter in order to cause its molecules to move to and fro.

We have also seen that a moving mass cannot stop moving until it loses all the energy that has been given to it to set it into visible motion. A moving mass differs from a mass at rest in that it contains both matter and energy; it must lose its energy before it can come to rest. A hot body also differs from an absolutely cold body in the fact that it contains both matter and energy. Before its molecules can stop moving, they must give off all their energy to the matter around them. *Heat, therefore, is not a kind of matter, but is a form of energy.* One body is hotter than another because its molecules have greater energy of motion.

142. Illustrations.—If a nail be struck a few sharp blows with a hammer, it will become too hot to hold in the hand. Here the energy of the hammer has been given to the molecules of the nail, and, setting them into motion, has heated the nail.

Two pieces of wood, if rubbed briskly together, become heated. The axles of cars sometimes become heated red hot by friction. If a blunt tool be firmly pressed against a piece of wood which is rapidly turning in a lathe, the friction develops sufficient heat to burn dark rings in the wood.

143. Expansion a General Effect of Heat.—Nearly all bodies, when heated, expand. They expand because their molecules move through greater distances to and fro when hot than when cold.

Matter, therefore, expands when heated, and contracts when cooled.

144. Thermometers.—The temperature of bodies is determined by means of a thermometer, an instrument that depends for its operation on the fact that bodies expand by heat and contract by cold. The thermometer consists of a glass tube, *A B*, Fig. 56, having a very small bore. This tube is closed at the top, and widened at its lower end into a bulb, *C*. The bulb, *C*, and part of the tube contain mercury. When the thermometer is taken into a warm place, the mercury, expanding, rises in the tube; but if taken into a cold place, it contracts and falls in the tube.

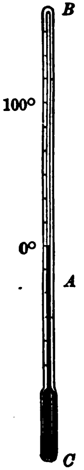


Fig. 56. Centigrade.

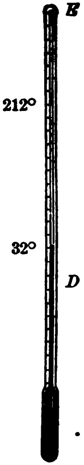


Fig. 57. Fahrenheit.

145. Construction of a Thermometer.—In order that the mercury in a thermometer may rise easily, care must be taken to remove all the air from the tube. This is readily done as follows: the mercury is placed in the bulb, *C*, and while the end, *B*, of the tube, Fig. 56, is still open, the mercury in the bulb is gradually heated until, by its expansion, it begins to run out at the open end, *B*. At this moment the heat is removed from *C*, and the end, *B*, melted, and thus effectually sealed. As now the mercury cools and contracts, it falls in the tube and leaves an empty space above it.

146. The Division of the Thermometer-Tube into Degrees.—We must now divide the tube of the thermometer into degrees, so as to know how hot or cold places are into which the thermometer is taken. To do this, we plunge the bulb, *C*, into melting ice, and when the mercury has acquired the temperature of the ice, and no longer falls, we mark on the tube the level at which it stands. We then expose the bulb to the steam escaping from boiling water, and mark on the tube the level to which the mercury rises, when it has acquired the temperature of the steam.

The points so obtained are called, respectively, the *freezing-point* and the *boiling-point of water.*

There are two thermometer scales in common use, called the Fahrenheit and the Centigrade. In the Fahrenheit scale, Fig. 57, the freezing-point is marked 32° and the boiling-point 212°. In the Centigrade scale, Fig. 56, the freezing-point is marked 0° and the boiling-point 100°. Centigrade means one hundred steps or degrees, and is so named because there are 100 degrees between the freezing- and the boiling-points.

The position of the freezing- and boiling-points being determined, the length of the tube between them is now divided, in the Fahrenheit scale, into 180 equal parts, called degrees, and in the Centigrade scale into 100 equal parts, and the length of the degree so determined, continued above the boiling-point and below the freezing-point. Degrees of Fahrenheit's scale are represented by an F. or Fah., those of the Centigrade scale by a C., thus, 34° F. or 60° C.

Since 180° F. = 100° C., 1.8° F. = 1° C. *Therefore, to change Centigrade degrees into Fahrenheit degrees, multiply by* 1.8 *and,* because the freezing-point of the Fahrenheit scale is 32° above the zero, *add* 32. Thus, if a Centigrade thermometer stand at 100°, how many degrees will a Fahrenheit thermometer indicate? Here 100° × 1.8° = 180°; and 180° + 32° = 212° Fah.

To change Fahrenheit degrees into Centigrade degrees, subtract 32 *and divide by* 1.8. What temperature of the Centigrade scale is the same as 212° F.? Here 212 — 32 = 180; and 180 ÷ 1.8 = 100° C.

Problems.—(48.) A thermometer stands at 33° C.; what would be the height of a Fahrenheit thermometer at the same temperature?

(49.) Convert a temperature of 83° C. into Fahrenheit degrees.

(50.) Convert the following temperatures of the Centigrade scale into those of the Fahrenheit scale; viz.:

Mercury	boils at	350° C.	Copper	melts at	1100° C.
Turpentine	"	156° C.	Zinc	"	410° C.
Acetic Acid	"	118° C.	Lead	"	334° C.
Alcohol	"	78.4° C.	Phosphorus	"	44° C.

(51.) Water has its temperature of greatest density at 39°.2 F.; what is the temperature of its greatest density in Centigrade degrees?

147. The Uses of a Thermometer.—We cannot rely on our feelings to determine how hot or how cold bodies are. If in winter we come into the entry of a house, from the cold street, the entry will feel warm; if, on the contrary, we pass from the warmer dining-room into the same entry, the entry will feel cold, although its temperature may not have changed in the meantime.

Experiment (62).—Partly fill three basins with water; one with water as hot as the hand can bear; another with quite cold water; and the third with tepid water. Plunge the right hand in the hot water and the left hand in the cold water, and keep them there for a little while. Now remove them and plunge both into the tepid water. Observe that the right hand now feels cold, because it is losing heat faster than it is receiving it; but that the left hand feels warm, because it is gaining heat faster than it is losing it.

148. Expansion of Solids.—*Solids expand by heat less than liquids. Liquids expand by heat less than gases.*

Solids differ very greatly in the amount they expand when equally heated.

Zinc, lead, and tin are among the most expansible of the metals, and steel and platinum among the least.

When solids expand or contract by changes of temperature, they exert considerable force. The tires of wheels are made too small to go on the wheel when cold. They are heated until large enough to slip on the wheel, and, when afterwards cooled, contract and hold the parts of the wheel firmly together. Were not the iron rails of railways laid so as to leave some little distance between their ends, they would on expanding, in warm weather, exert sufficient force to twist themselves from the wooden ties.

Thick glass-ware is very apt to break if suddenly heated or cooled. Pouring hot water into a cold glass tumbler is very apt to break the tumbler, because the inside expands before the outside can get warm.

149. Expansion of Liquids.— Most liquids expand when heated, and contract when cooled, no matter what the temperature may be. Water within certain limits also expands when heated and contracts when cooled; but when cooled to the temperature of 39.2° F., *water will expand whether heated or cooled;* if heated, *it will become lighter and warmer;* if cooled, *it will become lighter and cooler.* Water cannot, therefore, by mere change of temperature, be made denser than the density it has at 39.2° F. This is called the *temperature of the maximum density of water.*

When any body of water, such, for example, the lake shown (in section) in Fig. 58, is exposed to cooler air, its surface water is cooled, when, becoming heavier, it falls and is replaced by some lighter, warmer water. This process continues until the whole body of water is cooled to 39.2° F., when it is as dense as it can become by mere change of temperature. The surface layers, when still further cooled, expand, and remain on the surface; and this continues, and at last a layer of ice is formed. Water is a very poor conductor of heat; therefore, the lower layers remain at the temperature of 39.2° F., and, unless the weather is cold for a long while, remain unfrozen.

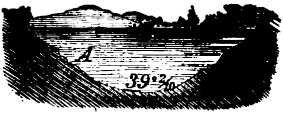


Fig. 58.—Effect of Maximum Density on Freezing.

150. Expansion of Gases.—The expansion of most gases is very nearly the same in amount as that of common air.

When any mass of gas, as, for example, a part of the atmosphere, is heated, it expands and, being lighter than the surrounding air, rises, while the cooler air blows in from all sides towards the place from which the heated air has risen. *This is the cause of winds.* This is also the cause of the draught in a chimney. The heated air in the chimney rising, causes the cooler air to rush through the fire into the chimney.

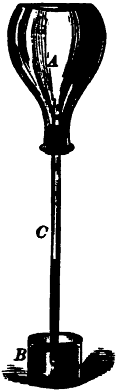


Fig. 59.—Expansion and Contraction of Air.

Experiment (63).—Cut a flat spiral from a sheet of paper, and, tying a piece of string to its end, hang it over the top of a heated stove or over a lighted lamp. Observe that the rising currents of heated air will cause the spiral to turn.

Experiment (64).—A bottle, *A*, of thin glass has fitted into it a glass tube, *C*, open at both ends. Hold the bottle for a few moments near a fire, and then quickly place it in the position shown in Fig. 59, by dipping the open end of the tube beneath a surface of blue water in the vessel, *B*. Observe that as the air in the bottle, *A*, contracts, the pressure of the atmosphere will cause the colored liquid in *B* to rise in the tube; but when *A* is heated, that the expansion of the air causes the column of liquid to fall.

SYLLABUS.

The heat of a body is caused by swinging movements of its molecules towards and from one another.

A heated body throws off its heat, and thus transmits it to surrounding bodies, by means of wave-motion given to a very elastic and exceedingly light substance called the luminiferous ether.

Heat is not a kind of matter, but a form of energy.

Nearly all matter expands when heated and contracts when cooled.

Thermometers are used to measure temperature; they depend for their operation on the expansion of a liquid placed in a bulb and tube.

The space above the mercury in a thermometer-tube should be quite empty.

In dividing the scale of a thermometer into degrees, we first obtain the position of the freezing-point and of the boiling-point of water.

In Fahrenheit's thermometer, the freezing-point of water is 32°, and the boiling-point is 212°. In the Centigrade thermometer these points are 0° and 100°, respectively.

To change Centigrade degrees into Fahrenheit degrees, multiply by 1.8° and add 32. To change Fahrenheit into Centigrade, subtract 32 and divide by 1.8°.

We cannot rely entirely on our senses to determine differences of temperature, since the same body may feel hot and cold at the same time.

Solids expand less by heat than liquids, and liquids less than gases.

When solids expand or contract by changes of temperature, they exert considerable force.

Water acquires its maximum density, from contraction, at the temperature of 39.2° F. At this temperature it expands whether heated or cooled.

QUESTIONS FOR REVIEW.

What is the cause of heat? What is the difference between the cause of heat and the cause of sound?

What is meant by the luminiferous ether? By what means is heat transmitted or carried from place to place?

How do hot bodies give off their heat?

Explain what is meant by the sentence, "Heat is a form of energy, and not a kind of matter."

Give some instances in which mechanical energy is changed into heat energy.

What is the most general effect produced on matter by the action of heat?

Describe the construction of a thermometer. Explain the manner in which an empty space is obtained above the mercury in the tube. State the rule for changing Fahrenheit into Centigrade degrees. State the rule for changing Centigrade into Fahrenheit degrees.

How is the thermometer scale divided into degrees?

Describe an experiment in which a body is made to feel hot and cold at the same time.

Name some of the most expansible of the metals. Name some of the least expansible of the metals.

What effect has the temperature of the maximum density of water on the freezing of large bodies of water?

Explain the cause of winds. What is the cause of the draught of a chimney?

Describe an experiment illustrating the expansion and contraction of air.

CHAPTER XV.

THE COMMUNICATION OF HEAT. SURFACE ACTION.

151. Communication of Heat.—Heat may be communicated or passed from one body to another, or from one part of a body to any other part, in three ways; viz., by *conduction*, by *convection*, and by *radiation.* Heat is communicated through solids by conduction; through liquids and gases mainly by convection and radiation.

152. Conduction of Heat.

Experiment (65).—Take two bars, *A* and *B*, of copper and iron, of the same length and thickness, and stick small marbles on them with wax, in positions such as shown in Fig. 60. Suitably supporting the bars, apply heat, such, for example, that of an alcohol-lamp, to one end of each bar, as shown. Observe, 1st, That as the heat travels from one end of the bars to the other, the marbles fall off one after another, and, 2d, That the heat passes more rapidly to the far end of the copper bar than to the far end of the iron one.

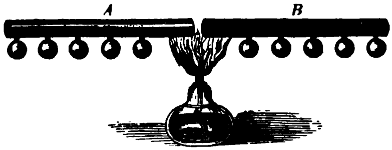


Fig. 60.—Unequal Conduction of Copper and Iron.

This passage of heat from one part of a substance to another part is called *conduction.* Substances differ in their powers of conduction. Some are good conductors, while others are very poor conductors. In the preceding experiment, the copper bar conducts heat better than the iron one. The molecules at the heated end gradually impart their motion to the molecules beyond them, until the body is heated throughout.

153. Examples of Conduction.—A poker left in the fire soon becomes too hot to handle. Irons for ironing clothes become heated throughout, and holders of cloth or wood must be used to enable them to be handled.

We wrap ourselves in blankets to keep warm; because the blankets are very poor conductors of heat, and keep the heat of the body from escaping. We wrap ice in blankets to keep it cold; because the blankets keep the outside heat from melting the ice. The polar bear and other animals which live in cold countries are kept warm by their coats of thick fur. Ice-houses are made with thick double walls, the space between the walls being filled with saw-dust and shavings, which are poor conductors of heat. Coffee- and tea-pots have wooden handles, which are poor conductors.

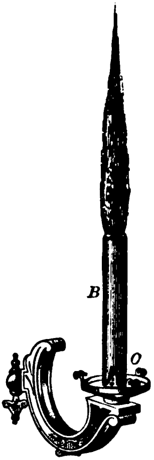


Fig. 61.—A Simple Bunsen Burner.

Experiment (66).—An alcohol-lamp, for heating bodies, can easily be made by boring a hole in a fine-grained cork, and inserting in it a small piece of glass tubing or bit of tin rolled into a tube. Pass a wick through the tube, and place the cork and wick in a bottle partly filled with alcohol.

Experiment (67).—Where illuminating gas is at hand, a more convenient source of heat is furnished by the *Bunsen burner*, one of which can be easily made as follows: Take a piece of tin in the shape of a rectangle, and cut out small rectangular pieces from one of its shorter ends, so that when the tin is rolled in the form of a tube, as shown at *B*, Fig. 61, there will be openings provided, as at *A*. Fit the end, *C*, loosely over a gas-burner. Turn on the gas, and light it from above. If the burner has been properly made, the flame will be bluish and almost non-luminous, and will not soot articles heated in it. Air enters at the openings below, and burns the gas more thoroughly than in an ordinary gas burner. This flame is very hot; glass tubes held in it may be softened and bent in any desired shape.

154. Conduction of Liquids and Gases.—Liquids are very poor conductors of heat, if the heat be applied at the surface. If the heat be applied from below, they are readily heated by the process called *convection*. Mercury, however, is an exception; though a liquid, it is a very good conductor of heat.

Gases are still poorer conductors of heat than liquids. Nearly all very porous substances are poor conductors of heat, because their pores are filled with air. This is the reason that such materials as wool and fur are so warm when used for clothing. Solids in a state of fine division are poorer conductors of heat than when not divided, for the same reason. Snow is a poorer conductor than ice; saw-dust and shavings are poorer conductors than the wood from which they are obtained.

155. Effect of Conducting Power on Apparent Temperature.—When a hot body is placed on a cold body, the rapidity with which the hot body becomes cold, that is, the rapidity with which it gives its heat to the cold body, is greater if the cold body is a good conductor of heat. In an unheated room, such as a bedroom, all objects have the same temperature; yet the rugs, carpets, and blankets feel warmer to the touch than does the marble of the table or mantlepiece, or the metallic knobs of the door; the rugs, carpets, or blankets are poor conductors, and conduct or carry away the heat of the body much more slowly than do the better conducting materials of the mantle, or table, or door.

156. Convection.—When heat is applied to the surface of a liquid, the upper layers, on becoming heated, expand, and remain on top, while the layers beneath them can only become heated by conduction. But liquids scarcely conduct heat downwards at all; therefore, the lower layers do not change much in temperature. If, however, the liquid be heated from below, then the lower layers expand when heated, and, thus becoming lighter than the rest of the water, rise, and are replaced by the colder water. This process, which is called *convection*, continues until all the liquid is heated.

When a liquid is heated from below, it is stirred about by the action of the heat, and soon becomes heated throughout.

To prevent burning, viscid liquids, like molasses or starch, must be stirred while heating, because they cannot flow as easily as mobile liquids.

A lump of ice thrown into a tumbler of water causes convection currents. The water which touches the ice is cooled, and becoming heavier falls, and is replaced by the warmer, lighter water. Fig. 62 shows the direction of these currents. By throwing some bran in the water, the currents can be easily seen.

Fig. 62.—Convection Currents.

157. Radiation of Heat.—If a hot body be held a short distance below the hand, we can easily see how the hot air, which rises from the body, could carry heat to the hand. But if the heated body be held *above* the hand, we shall still feel the heat. Here the heat cannot have been carried to the hand by means of currents of heated air. We shall also feel the heat of the body, if it be held on any side of the hand.

Hot bodies are constantly giving out their heat in all directions; this process is called *radiation.* Radiant heat is carried from hot bodies to surrounding bodies, by means of waves in the luminiferous ether. These waves are produced in the ether by the motions to and fro of the molecules of the heated bodies.

Bodies radiate their heat equally well in all directions; that is, the waves in the luminiferous ether, caused by a hot body, spread equally well in all directions, just as the waves caused by a sounding body spread through the air equally well in all directions.

If we stand in front of a stove whose door is shut, we will feel its heat equally well in all positions at the same distance from the stove, and a thermometer held in different positions, at equal distances from the stove, will show the same temperature.

The sun's heat reaches the earth, across the apparently empty space between the sun and the earth, by radiation, that is, by waves in the ether which fills all space.

Bodies radiate their heat, whether their temperature be the same as or different from that of surrounding bodies; for, as long as their molecules vibrate, they must set the ether around them in waves.

Heat is radiated in straight lines. The heat of the sun comes along with the sun's light. That this heat comes to us in the same straight lines in which the light moves, can be easily proved; for, if on a hot day we stand in front of a wall so that the sun's light is just cut off from us, that is, if we stand in the shadow of the wall, we will feel cooler than if in the sunshine; the wall, therefore, must cut off the heat just as it does the light.

158. Reflection of Heat.

Experiment (68).— Let some one hold a flat piece of bright sheet tin, or a polished tin plate, in front of an open fire so that the light from the fire will be thrown into the face. Observe that the face is warmed when the light is thrown into it; the heat, therefore, must have been thrown with the light from the plate into the face.

When the waves in the ether, which cause heat, strike against certain bodies, they are thrown off from their surface. This change in the direction in which the heat-waves are moving is called the *reflection of heat.* The reflection of heat-waves is similar to the reflection of sound-waves. *Bright, polished metals are good reflectors of heat.*

159. Absorption and Emission of Heat.—When the heat which falls on the surface of a body is not thrown off or reflected therefrom, it either passes through the body, like light passes through a piece of clear glass, or it passes into the body and heats it. In this latter case the body is said to *absorb the heat.* The heated body can then throw off its heat by radiation, and is then said to *emit the heat.*

All bodies that absorb heat readily also emit it readily. Dark, dull, rough surfaces are generally good absorbers or radiators of heat; smooth, brightly-polished surfaces are poor absorbers or radiators of heat, because they are good reflectors; for it can be readily seen that if a body throws most of the heat from its surface, of course but little can enter and be absorbed.

160. Illustrations.—Water heats more rapidly in an old tin vessel, which is dull or covered with soot, than in a new and brightly-polished one, because the heat is absorbed more readily by the first than it is by the second.

A dull, unpolished stove heats a room better than a smooth, brightly-polished one, because the first emits or radiates its heat better than the second.

Coffee or tea will remain hot for a much longer time in brightly-polished pots than in dull, tarnished ones, because the first emit or radiate heat less rapidly than the second.

SYLLABUS.

Heat may be communicated in three ways; viz., by conduction, by radiation, and by convection. Gases and liquids are heated mainly by radiation or by convection.

Solids are, as a class, better conductors of heat than liquids, and liquids better conductors than gases. Neither liquids nor gas conduct heat readily.

Substances differ very greatly in their ability to conduct heat.

Poor conductors of heat will, if wrapped around hot or cold bodies, enable them to remain hot or cold for a much longer time than if those bodies were exposed to the air.

Animals that live in cold countries are protected from the cold by thick coats of fur.

When air is mixed with common illuminating gas, the flame becomes less luminous, but much hotter, than before.

Substances, like fur, wool, saw-dust, or shavings, that contain much air between their particles, are very poor conductors of heat, because air is such a poor conductor.

Though at the same temperature, the carpets or rugs of a room feel much warmer to the touch than do the marble or metallic objects, because the former do not conduct or carry off the heat as readily as do the latter.

When liquids are heated from below, the heat is distributed through them by means of convection currents caused by some portions of the liquid becoming lighter than the rest.

A hot body throws off or radiates its heat by means of waves that its molecules cause in the luminiferous ether.

Bodies radiate their heat equally well in all directions. Radiant heat passes off from hot bodies in straight lines.

When heat-waves fall on bodies, they are either thrown off or reflected from them; or they pass through the bodies; or they are absorbed by the bodies and make them warmer.

Bright, smooth, polished metallic surfaces are good reflectors; dull, rough, or tarnished surfaces are poor reflectors, but good absorbers. Bodies that absorb heat readily, also emit or radiate it readily.

Good reflectors of heat are, necessarily, poor absorbers.

QUESTIONS FOR REVIEW.

In what three ways may heat be communicated?

Describe any experiment by which the conduction of heat may be shown. Do all substances conduct heat equally well? Why does a conducting substance, like a rod of metal, become heated throughout, when heated at one end only?

Give some instances in which poorly-conducting substances are employed to keep bodies warm. Can poor conductors also be employed to keep bodies cold?

Why are finely divided solid substances poorer conductors than when in one solid mass?

Why do not all bodies whose temperature is the same, feel equally warm or cold to the touch?

Define convection. What is the cause of the currents developed in liquids by heating or cooling them?

What is meant by the radiation of heat?

By what means is radiant heat carried from one body to another?

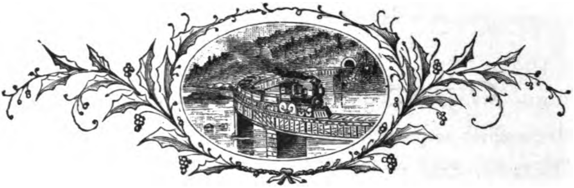
Does radiant heat pass more easily in one direction than in another? Prove that the radiant heat of the sun reaches the earth in straight lines.

Define reflection, absorption, and emission of heat. What kind of bodies are good reflectors? What kind are good absorbers or emitters? Why cannot good reflectors of heat be also good absorbers or radiators?

Why does water heat more readily in a dull, tarnished vessel than in a bright, polished one?

Why does a smooth, brightly-polished stove give out or radiate its heat less readily than a dull, tarnished one?

Why will coffee or tea keep warm for a longer time in bright, polished pots than in dull, tarnished ones?



CHAPTER XVI.

CHANGE OF STATE. LATENT HEAT. STEAM.

161. Effect of Heat on Matter.—Heating a solid substance causes it to expand. If the expansion be carried far enough, the body *melts* or *fuses*. As the liquid thus formed is heated, it also expands, and, if the expansion be carried far enough, passes off as a *vapor* or *gas*.

Solid substances differ in the ease with which they are fused or melted. Some, like butter or lard, require but little heat, while others, such as iron or copper, require the heat of a powerful furnace.

Liquid substances differ also in the ease with which they are caused to pass off as vapor.

162. Latent Heat.—Heat is required to melt ice or to boil water, but the heat passed into ice to melt it, or into water to cause it to boil, does not raise the temperature after the ice once begins to melt, or the water to boil. Thus, if we pack melting ice around the bulb of a thermometer, the thermometer will show a temperature of 32° F. If we pass heat into the ice, it will melt; but neither the ice which is unmelted, nor the water which comes from the melted ice will become any warmer than before; the temperature of both is still 32° F.

Water when raised to the temperature of 212° F. begins to boil; to cause it to continue to boil, we must continue to pass heat into it; but this heat neither makes the water itself, nor the steam or vapor rising from it, any hotter than before. Both still have the temperature of 212° F.

What has become of the heat in either case? It has disappeared as heat-energy. It no longer causes an increase of temperature, and assumes the form which is sometimes called *latent* or *hidden heat.*

163. Nature of Latent Heat.— If a weight attached to a string passing over a pulley, be raised from the ground, a certain amount of energy is expended. If now the string be fastened so that the weight remains suspended in the air, the weight does no work except to stretch the string. It may remain suspended for years, but if at any moment the string be cut, the weight in falling will give out an amount of energy equal to that required to raise it.

When a solid melts, or a liquid passes into a gas or vapor, the molecules undergo a considerable change of position. To give them this change of position, energy is expended, just as it is expended to raise the weight. While the liquid remains a liquid, or the gas remains a gas, this energy is doing no work, but as soon as the liquid again becomes a solid, or the gas or vapor again becomes a liquid, all the energy again reappears. The heat which disappears during the melting of a solid, or the evaporation of a liquid, becomes latent, because the energy is absorbed in order to give the molecules a change of position. But when the molecules fall back again into their former positions, that is, when the liquid again becomes a solid, or the gas or vapor a liquid, all this energy again reappears as heat, and hence just as much heat must become sensible as was previously rendered latent.

When a solid melts or a liquid evaporates, considerable heat disappears or becomes latent.

When a liquid is turned into a solid, or a gas or vapor into a liquid, considerable heat appears or becomes sensible.

164. Freezing Mixtures.— When salt is thrown on ice or snow, both the ice or snow and the salt melt rapidly. Anything put in a mixture of this kind becomes very cold. The reason is simple; for the salt and ice to melt, heat must disappear; this heat is taken from the mixture, which therefore becomes cold. Ice-cream is frozen by placing the cream in a tin vessel surrounded by a freezing mixture. To keep the freezing mixture cold, it is placed in a wooden vessel, which is a poor conductor of heat.

165. Production of Cold by Evaporation.— On hot days in summer, when the air is very oppressive, we find relief by fanning, although the movements of the fan bring the hot air more rapidly against the body. The reason is as follows: the perspiration of the body is constantly passing off as vapor; but for vapor to be formed, heat must disappear, and this heat is taken from the body, which is thereby cooled. Now fanning causes the vapor to pass off more rapidly, and therefore cools the body more rapidly.

166. Vaporization of Liquids.—Liquids may vaporize, that is, pass off as vapor, either from the surface only, in which case the process is called *evaporation;* or the vapor may pass off from below the surface as well, in which case it called *boiling*, or ebullition.

167. Evaporation. The Moisture of the Atmosphere.— Vapor is always present in the atmosphere; for, it is constantly passing into the air from the ocean, seas, lakes, rivers, and, in fact, from every water surface on the earth.

Warm air can hold more moisture in an invisible state, as vapor, than cold air. Therefore, evaporation takes place more rapidly in summer than in winter, and is always greater in the equatorial than in the polar regions. Evaporation is greater, the more extended the surface from which the vapor is escaping. Evaporation is greater on windy days than on calm days; it also occurs more rapidly when the air is dry, and the atmospheric pressure is moderate.

When air has in it as much vapor as it can hold, it is said to be at its *dew-point*, or *point of saturation.*

If air at its dew-point be made warmer, it becomes relatively drier, because its capacity for moisture is thereby increased. But if air at its dew-point be made cooler, some of its invisible vapor becomes visible as fogs, clouds, dew, rain, hail, or snow.

Therefore, to cause fogs, clouds, dew, rain, hail, or *snow to be deposited from the air, its temperature must be made colder than the dew-point.*

168. Ebullition or Boiling.—Many liquids, such, for example, as water, evaporate at nearly all temperatures. But the temperature at which any liquid boils is always the same for the same liquid, provided the pressure on the surface of the liquid be not changed. If, however, the pressure increase, the temperature required for the boiling of the liquid will also increase; but if the pressure decrease, the temperature of the boiling-point will also decrease.

The greater the pressure on a mass of water, the higher the temperature of its boiling-point; the smaller the pressure, the lower the temperature of its boiling-point.

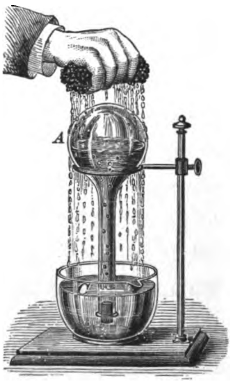


Fig. 63.
The Culinary Paradox.

Experiment (69).—An experiment, sometimes called the culinary paradox, may be shown to prove that a diminished pressure lowers the temperature of the boiling-point. Water is boiled in a thin glass flask, *A*, Fig. 63, and after a few minutes of vigorous boiling, so as to let the steam drive all the air out of the flask, the source of heat is removed, and the neck is closed by a tightly-fitting cork, which has been previously steeped in melted wax or paraffin, so as to fill all its pores. The vessel is now inverted below a water-surface, *C*, to prevent the entrance of air. For a few moments the water will continue to boil; but the increased pressure on the surface, produced by the confined vapor, soon *raises the boiling-point and stops the boiling.* Now let some cold water fall on the bottom of the flask, as shown. The vapor will then be condensed, and the pressure being diminished, the liquid will burst into vigorous boiling. Pour hot water on the flask, and the water will again stop boiling.

When a liquid begins to boil, its temperature remains the same until all the liquid has been turned into vapor. Water boils at 212° F. Hence, any vessel containing boiling water cannot readily be raised much above 212° F. An empty coffee-pot, left on the fire, will soon fall to pieces from the melting of its soldered joints, but filled with coffee, it can safely be left on even a very hot fire. We can further illustrate this principle by a very curious experiment.

Experiment (70).— To boil water in a paper bag. Take a square piece of paper and fold it so as to form a conical bag, *A*, as shown in Fig. 64. Suspend the bag by strings, and, pouring water into it, allow the flame of an alcohol-lamp or Bunsen burner to fall on the bag, being careful to prevent the flame from touching the paper in any place where there is no water. The water can now be heated until it boils, without the paper being burned, because the paper cannot be heated much more than 212° F., which is not sufficient to burn it.

Fig. 64.
Water Boiled in a Paper Bag.

When it is necessary to make water very hot so as to cause it to extract or dissolve glue from bones, etc., it is heated in strong vessels, from which the steam is prevented from escaping. In such cases the pressure on the surface of the water increases, and therefore raises the temperature of the boiling-point.

169. Steam.—Steam is the vapor that escapes from boiling water. Steam, like all vapor from water, is invisible. The white clouds we see escaping from boiling water are not real steam, but condensed vapor, and consist of very small drops of water, such as form mists, fogs, or clouds.

Steam may be made to exert considerable pressure, especially when it escapes from water whose boiling-point has been raised by the water being boiled in a closed vessel. Its use in the steam-engine is well known. On being let into a hollow cylinder with a movable piston, something like that shown in Fig. 33, the steam pressing against the piston pushes it to one end of the cylinder; at this moment the steam is cut off from this side of the piston and let into the cylinder on the other side of the piston, when it drives it to the other end of the cylinder. These motions of the piston from one end of the cylinder to the other, are, by suitable means, changed into a rotary motion, by means of which the engine can be made to drive machinery.

SYLLABUS.

Most solids, when sufficiently heated, melt or fuse. Most liquids will, when sufficiently heated, vaporize.

Ice at 32° F. requires heat to melt it, and yet the water formed from the melting of the ice is no warmer than 32° F.

Water at 212° F. requires heat to boil it, and yet the steam or vapor which escapes from it is no warmer than 212° F.

The heat required to cause ice at 32° F. to melt, or to cause water at 212° to boil and form vapor, is no longer able to cause a change of temperature, and is therefore said to be latent or hidden.

In order to raise a weight from the floor to the ceiling, energy must be expended or caused to disappear. When this weight falls to the floor, the energy again appears. In order to give the molecules of solids or liquids the change of position necessary to cause them to become liquids or vapors, energy must be expended or disappear. When the liquid again becomes a solid, or the vapor again becomes a liquid, this energy reappears as heat.

The passage of a liquid into vapor is called vaporization; when the vapor only escapes from the surface of the liquid, the process is called evaporation; when it escapes from beneath as well as from the surface, it is called boiling. Vapor may be precipitated from the air as fogs, clouds, dew, rain, hail, or snow.

The temperature of the boiling-point increases as the pressure increases, and decreases as the pressure decreases.

When any liquid has been heated to the temperature of its boiling-point, its temperature remains the same until all the liquid has been changed into vapor. Hence the temperature of the vessel which holds the liquid, never rises much above the boiling-point of the liquid.

Steam is invisible. What most people call steam is minute drops of water like those which form clouds.

QUESTIONS FOR REVIEW.

When is a substance said to melt or fuse? When is it said to evaporate?

What is meant by latent heat? When is heat rendered latent? When does the latent heat, so called, again appear as heat? Why must as much heat appear as has been rendered latent?

Explain the similarity that exists between the energy expended in raising a weight and that expended in causing a solid to become a liquid, or a liquid to become a vapor. How may the raised weight again give out the energy it has received? How may the fused solid or the vaporized liquid again give out the energy it has absorbed or caused to become latent as heat?

Why do mixtures of ice and salt or snow rapidly become so cold?

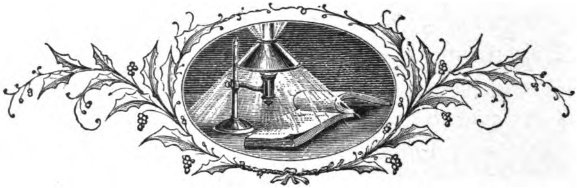
Why does fanning cause us to feel cool?

Define vaporization. Distinguish between evaporation and boiling.

Describe the experiment called the culinary paradox. What is this experiment intended to illustrate?

Why does an empty coffee-pot fall to pieces when placed on a fire where a filled pot can be safely left?

Describe the experiment of boiling water in a paper bag.



CHAPTER XVII.

THE NATURE AND SOURCES OF LIGHT. ACTION OF MATTER ON LIGHT.

170. The Cause of Light.—When a body is sufficiently heated, it gives off light as well as heat. As the temperature increases, the molecules move to and fro more and more energetically, and cause waves in the luminiferous ether. These waves move outwards from the hot body in all directions, and, when they enter the eye, cause the sensation of light.

Light, then, like heat, is caused by a wave-motion in the luminiferous ether; like heat, too, it is one of the forms in which energy may manifest itself, and is not a kind of matter.

171. Sources of Light.—The sun and the stars are our principal sources of light; nearly all our artificial light is obtained from the burning of different bodies, or from electricity.

172. The Cause of Vision.—Bodies are visible, that is, we see them, by means of the light they throw off. In a dark room nothing can be seen; but if we light a candle, objects at once become visible, because the light from the candle falls on the bodies, and is thrown off from them and enters our eyes. Bodies like the candle, that throw off their own light, are said to be *luminous;* bodies that throw off the light they receive from luminous bodies are said to be *illumined.* Nearly all objects we see are illumined, and receive their light from the sun or some other luminous body.

173. Opaque, Transparent, and Translucent Bodies.—If a book be held between our eyes and any visible body, we can no longer see the body, because the light which it throws off cannot pass through the book. If, however, we hold a piece of clear window-glass between our eyes and the visible body, we can still see the body, because the light it throws off passes through the glass and enters our eyes. Substances like the book, that do not allow light to pass through them, are called *opaque* substances; those like the piece of clear glass, that allow the light to pass through them, so that we can clearly see objects beyond, are called *transparent* substances. If, however, the surface of the glass be roughened, as in ground glass, although considerable light can pass through, yet we cannot see the outlines of bodies beyond the glass; such a substance is called a *translucent* substance. Oiled paper is a translucent substance.

174. Light Moves in Straight Lines.—When light enters a dark room through a moderately small hole, we can, if the air of the room be dusty, see that the light moves into the room in a straight line.

Experiment (71).—Darken the room as much as possible, and then allow the light to enter through a small hole in the shutter or curtain. Rub two black-board rags together so as to make the air dusty. Observe that the light passes in a perfectly straight path through the dusty air.

Experiment (72).—After the chalk-dust has settled, stretch a string in the direction in which the light was observed to enter. Observe that the string is illumined throughout its entire length. Now stretch the string in some other direction, and note that it will only be illumined when it is held in the straight line in which the light was seen to enter the room.

A single line of light is called a *ray;* a number of parallel rays is called a *beam;* the rays which come from any luminous or illumined point are called a *pencil.* In a *diverging pencil*, the rays are all moving from one point; in a *converging pencil*, they are all moving towards one point.

175. Shadows.—When an opaque body is held in the path of light from any source, it cuts the light off, and leaves a shadow where the light cannot fall. Thus, in Fig. 65, suppose *s* is a luminous point and *A* an opaque ball. Then in the space back of *A*, where the light cannot fall, a shadow is seen. If the luminous point is at *s′*, nearer the ball, the shadow becomes larger, and lies within the direction of the rays *s′ a a′* and *s′ b b′*, which just graze the edges of the ball.

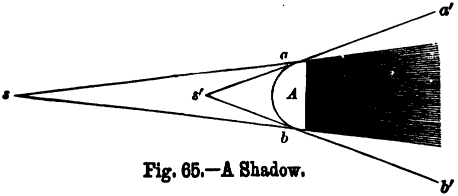


Fig. 65.—A Shadow.

Shadows generally have the outlines of the bodies that cast them. This proves that light must travel or move in straight lines.

Experiment (73).—Hang a wet sheet from the ceiling, preferably in an open doorway leading into an adjoining room, so as to act as a curtain or screen. Place a lighted candle on the floor back of the sheet, and then walk backwards and forwards between the candle and the sheet. Observe that very curious and grotesque shadows appear to those on the other side of the sheet, without their being able to see how they were caused. While walking towards the candle, the shadow rapidly increases, and while walking away from it, rapidly decreases in size. By stepping over the candle, the shadow appears to be leaping through the ceiling.

176. Velocity of Light.—Light moves with the almost inconceivable velocity of 185,000 miles in a second of time; a speed that, if it moved in a curved path, could carry it more than seven times around the earth at the equator in one second.

177. Actions which Occur at the Surfaces of Bodies.—The light which falls on bodies is either thrown off from their surfaces, or passes into their substance; that thrown from the surfaces is either *diffused* or *reflected;* that which enters may pass out again, in which case the bodies are transparent or translucent. If it enters the body and does not pass out again, the light is said to be *absorbed.* Absorbed light is generally changed into heat.

178. Diffusion of Light.—When light is thrown off from the surfaces of bodies in all directions, it is said to be diffused. All illumined bodies diffuse light, that is, scatter it in all directions.

179. Reflection of Light.

Experiment (74).— Place a mirror, or small piece of looking-glass, on a table in a darkened room, so that a beam, *A B*, of sunlight coming through a hole, *A*, Fig. 66, in the shutter may fall on it in the direction shown. Observe that, after striking the mirror, the light changes its direction and flies off the plate and strikes the ceiling in the direction *B C.*

Experiment (75).—Hold the plumb-line shown in Fig. 18 so that the end of the plumb is directly over the spot on the plate where the light strikes it, and the string supporting it, therefore, takes the direction of the vertical line *D B*, Fig. 66. Observe that when the light leaves the mirror, the ray is as much turned away from this vertical line as it was turned towards it before it struck the mirror; that is, that the angle *ABD*=*DBC.*

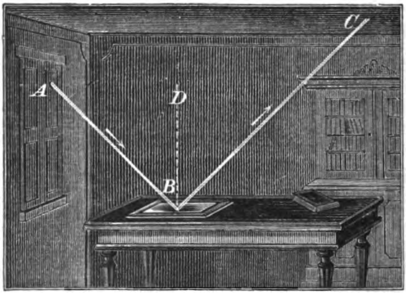


Fig. 66.—Reflection of Light.

The change in the direction of light, caused by its being thrown from the surfaces of bodies, is called *the reflection of light.* It is similar to the reflection of sound or of heat.

The angle, *A B D*, at which the light strikes is called the angle of *incidence*, which means the angle of striking. The angle, *D B C*, at which it is reflected is called the angle of reflection.

In the reflection of light, heat, and sound, the angle of reflection is always equal to the angle of incidence.

Highly-polished surfaces of glass or metal are good reflectors of light. The surface of a quiet body of water will reflect the light, especially if it strike the surface very obliquely. When the sun is near setting, or shortly after it has risen, its light is quite dazzling when reflected from a water surface.

Experiment (76).—Darken the room and allow a beam of light to enter through a hole in the shutter. Hold a small mirror in the path of the beam. Observe that, by differently inclining the mirror, the light may be thrown into any part of the room, as, for example, on a distant clock, or printed card. If smoke or dust be present in the room, the path of the reflected light can be distinctly seen. The same experiment may be shown in a lighted room, but, since the path of the beam is invisible, the effect is not so impressive.

180. Refraction of Light.

Experiment (77).—Darken the room and allow a beam of light to enter. Instead, however, of letting it fall on the mirror, *B*, as in Fig. 66, place on the table a large glass vessel filled with water, the surface of which may be seen at *S B*, Fig. 67. Observe that when the beam, *A B*, strikes the surface of the water at *B*, a part of the light is reflected in the direction *B C*, and that a part enters the water, but that, instead of continuing through the water in the same straight line, *A B F*, it is bent out of this direction and passes through the water in the direction *B G*.

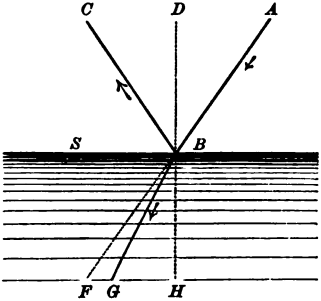


Fig. 67.—Refraction of Light.

This change in the direction of a ray of light, caused by its entrance into a transparent medium, is called the *refraction of light*. The angle *A B D* is, as before, called the angle of incidence and *H B G*, the *angle of refraction*.

When light enters a transparent substance at right angles to its surface, it is not changed in its direction.

181. Effects of Refraction.— A straight stick dipped obliquely into clear water appears bent where it enters the water. This is caused by the refraction of the light as it leaves the water.

Experiment (78).— Place a coin, *a*, in the bottom of an empty bowl, *A*, Fig. 68, and standing so as just to see the coin *over the edge*, *b*, *of the basin*, move the head back until the coin just disappears. Then let some one quietly pour clear water in the basin, and the ray of light which just grazes the edge will be bent as it passes out of the water, and, taking the direction *b c*, will enter the eye of the observer, who will see the coin in the position *a′*. Observe that, besides changing the direction of the ray, refraction in this case causes the coin to appear nearer the surface of the water than it really is.

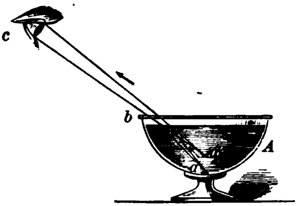


Fig. 68.— An Effect of Refraction.

To an observer standing on the margin of a stream of clear water, and looking at objects on the bottom of the stream, the water appears less deep than it really is. Many an inexperienced trout-fisher, through ignorance of this principle, has stepped into water much deeper than he expected.

182. Intensity or Brightness of Light.— The nearer we are to a luminous body, the brighter will its light appear. The intensity of its light decreases as the square of its distance. When we go twice as far from a luminous body, the intensity of its light becomes but one-fourth what it originally was; at three times the distance, the intensity is one-ninth.

The intensity of the light diminishes because the rays of light diverge from the luminous point, as *S*, Fig. 69, and spread wider and wider apart as the distance from *S* increases. Thus, at *A*, say one inch from *S*, a certain amount of light from *S* just illumines the surface of *A*, say one square inch. At *B*, two inches from *S*, or twice as far as *A*, the same quantity of light would illumine a surface, *B*, four times as great as *A*; therefore, the brightness of the light on any square inch of *B* must be but one-fourth as great as that on *A*. At *C*, three times the distance from *S* as *A*, the light would illumine a surface of nine square inches, and the brightness of the light on any one of these square inches would be but one-ninth the brightness at *A*. So at *D*, four times the distance of *A*, the surface covered would be sixteen square inches, and the brightness but one-sixteenth that at *A*.

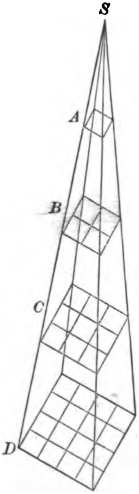


Fig. 69.
The Intensity of Light.

Problems.—(**52.**) If the intensity of the light at three feet from a candle be two, what will be its intensity at a distance of twenty feet?

(**53.**) How much will the intensity of a light decrease, if the distance from it be increased 100 times?

(**54.**) If the intensity of a light at the distance of ten feet be one, what will its intensity become at the distance of one mile?

* * *

SYLLABUS.

Light is a form of energy, and not a kind of matter.

Light is caused by a wave-motion in the luminiferous ether, produced by the shakings to and fro of the molecules of luminous bodies.

The sun, the stars, burning bodies, and electricity are our principal sources of light.

When the light which is thrown off from a body enters our eyes, we see an image of the body from which the light comes.

Transparent substances are such as allow light to pass through them so as to permit us to clearly see bodies beyond.

Translucent substances are such as allow light to pass through them, but not in such a manner as to permit us to see bodies beyond.

Opaque substances are such as do not allow light to pass through.

Light moves in perfectly straight lines, but when reflected or refracted, changes the direction in which it moves.

When the light is prevented from moving in any direction because an opaque substance is in its path, a shadow is left where the light cannot fall.

Shadows generally have the same outlines as those of the bodies which cast them.

Light moves with a velocity of 185,000 miles per second.

The light which falls on a body may be thrown off from its surface by reflection or diffusion; or it may enter the substance, when it is either absorbed or refracted; or it may pass through the substance, if the body be transparent or translucent.

When light is reflected from a body, the direction of the light is changed. The angle of reflection is always equal to the angle of incidence.

When light enters a transparent substance obliquely to the surface, it is refracted or bent out from the direction in which it was coming into the substance.

Objects partly immersed in water appear bent or broken where they enter the water obliquely.

The intensity of light decreases as the square of the distance from the source.

QUESTIONS FOR REVIEW.

What is the cause of light? Is light a form of energy or a kind of matter?

Name the principal sources of light.

Explain the cause of vision. Define luminous and illumined bodies.

Define transparency, translucency, and opacity.

Name some transparent substances. Name some translucent substances. Name some opaque substances.

What proofs have we that light moves in straight lines? Describe any experiments which prove that light moves in straight lines.

Define ray of light; pencil of light; beam of light.

Explain the cause of shadows. Do not the forms of shadows prove that light moves in straight lines?

What is the velocity of light?

Define diffusion of light; absorption of light.

Define reflection of light. What is meant by the angle of reflection? To what is the angle of reflection always equal?

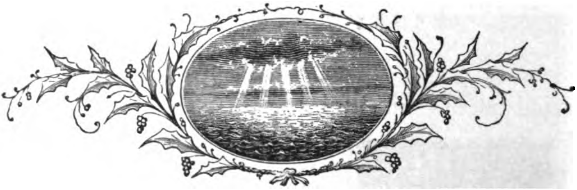
Describe any experiment which illustrates the reflection of light.

Define refraction of light. What is meant by the angle of refraction?

Mention some of the effects of refraction.

Why do objects seen in clear water appear to be nearer the surface than they really are?

Define intensity or brightness of light. What effect has an increase of distance from the source of light on its intensity?



CHAPTER XVIII.

THE FORMATION OF IMAGES. VISION. COLOR.

183. Formation of Images by Small Openings.

Experiment (79).— Allow the sunlight to pass through a hole in the shutter of a darkened room and fall on a piece of white paper, held at right angles to the direction in which the light is entering the room. Observe that a round disc of light will be seen on the paper. This is the image of the sun.

Experiment (80).—Paste a smooth, flat piece of tin-foil over a hole in a postal card, and punch a hole in the middle of the foil with a large needle or awl. Tack the card over the hole in the shutter of a darkened room, and allow the diffused light from the trees, houses, or other objects outside, to fall on a screen held opposite the hole. Observe that an image of the objects on the outside will be seen on the screen, but that the objects seen, will all be turned upside down.

The reason everything seen in this way appears upside down is simple. Suppose *O*, Fig. 70, is the opening; then a ray of light from, say the top of the steeple, would, in passing through the opening, fall on the lower part of the screen, *B*, and make an image there of this part of the church. The rays from the lower parts of the church would, in like manner, in passing through *O*, fall near the top of the screen. In this way all objects outside the room would appear inverted on the screen.

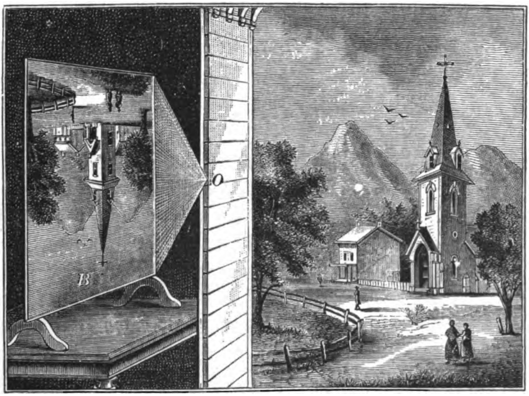


Fig. 70.—Images Formed by Small Openings.

184. Direction in which Images are Seen.—We always see a body in the direction in which its light enters our eyes. We can see an image of anything, such, for example, a candle, *A B*, placed, as in Fig. 71, before a looking-glass, as though it were back of the looking-glass, because the light from any part of the candle, as the flame, *A*, is turned out of its direction by reflection from the glass, and, entering the eye, causes us to see an image at *A′* in the direction these rays enter the eye.

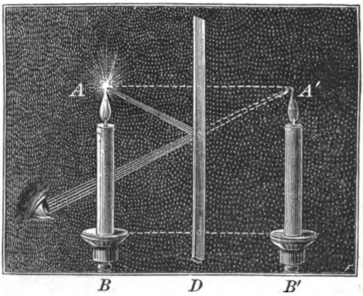


Fig. 71.—Images Seen in a Plane Mirror.

Images seen in a plane mirror appear of their natural size, and seem to be as far behind the mirror as the objects which cause them are in front of it.

The fact that the eye sees an image in the direction in which the rays enter it, can be amusingly shown by the following experiment.

Experiment (81).—By placing four small pieces of looking-glass at *a*, *b*, *c*, and *d*, as shown in Fig. 72, a ray of light from a distant object, *A*, will, after reflection from the mirrors, enter the eye at *C* in the same direction as that in which it came from the object. The eye, therefore, will see the distant object, although an opaque body, such as a brick, be held at *B*, between the eye and the object, thus making it appear as though the person was seeing through the brick. The mirrors may be concealed in a suitably shaped box, with openings at *A* and *C*.

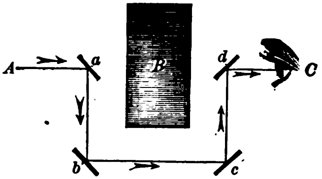


Fig. 72.—Looking through a Brick.

185. The Visual Angle.—If an object, *A A*, be placed in front of the eye, the rays of light from the extremities of the object entering the eye at *O*, will make an angle, *A O A*, which is called the *visual angle*. If the size of the visual angle varies, the size that the object appears to us will also vary. The larger the visual angle, the larger the object will appear. If the object, *A A*, be taken further from the eye, as, for example, to *A′A′*, it will appear to be smaller, because it is seen under a smaller visual angle.

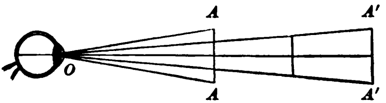


Fig. 73.—The Visual Angle.

Any cause which alters the visual angle under which an object is seen, alters its apparent size.

If, for example, a person hold a curved mirror, such as shown in Fig. 74, near his face, he will see a magnified image of his face, because the rays from any part, such as *a*, after reflection from the mirror, enter his eye under a different visual angle than they would if he were in front of a plane mirror. This causes him to see a magnified image of this part of his face at *a′*, in the direction the light enters his eye after reflection from the mirror. In like manner, the rays from *b* produce a magnified image at *b′*.

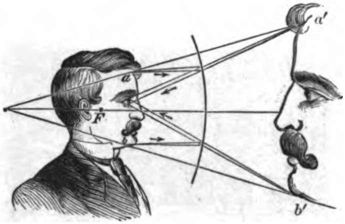


Fig. 74.
Magnified Image Seen in Curved Mirror.

If, however, the object be placed a little further from the curved mirror, as, for example, in the position of the candle shown in Fig. 75, then the direction of the rays is so changed after reflection as to throw, on a screen at *A*, an inverted image somewhat larger than the object.

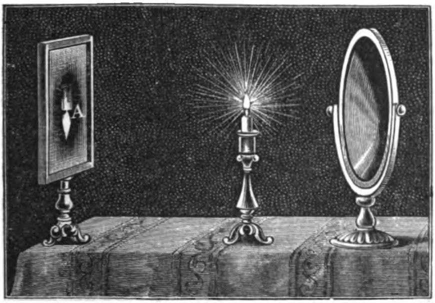


Fig. 75.—Inverted Image Caused by Curved Mirror.

186. Effect of Refraction on Apparent Direction.—If an object, such as the candle, *B*, Fig. 76, be looked at through a clear piece of glass, called a *prism*, shaped as at *A*, the rays of light from any part of the candle will, on passing through the prism, be changed in their direction by refraction, and, entering the eye as shown, will cause an image of this part of the candle to appear at *C*, *above its real position*, *B*. If, instead of looking through the prism when in the position shown in Fig. 76, with its edge, *a*, upwards, this edge be pointed downwards, the candle would then be seen *below its real position*, *B*.

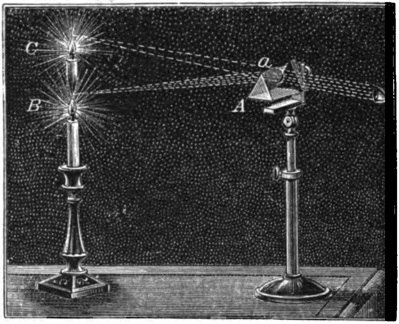


Fig. 76.—An Effect of Refraction.

187. Formation of Images by Lenses.—*Lenses* are transparent pieces of glass bounded by two surfaces, both of which are generally curved, but one of which may be plane. Rays of light, on entering and leaving a lens, are bent out of their course. Objects, therefore, seen through a lens will, as in the case of the prism, be seen out of their true position, and, whenever they cause the eye to see the image under a different visual angle from that under which it sees the object directly, will cause the apparent size of the image to be different from that of the object.

A very common form given to a lens is that shown at *C D*, in Fig. 77. This shape, it will be seen, is nearly the same as that which would be produced if another prism, like the one shown in Fig. 76, were placed with its edge corresponding to *a*, pointing downwards; that is, with the two bases together. If an object, such as a beetle, be placed near such a lens in the position *A B*, as shown in Fig. 77, the rays of light, coming from the parts near *A*, would be so bent by passing through the lens as to be seen by the eye, *E*, as though they came from *A′*, which is *above* *A*, and at a greater distance from the lens. In the same way, the portion near *B*, appears to be situated *below* *B*, at *B′*. The image of *A B*, therefore, appears greatly magnified, as shown at *A′ B′*.

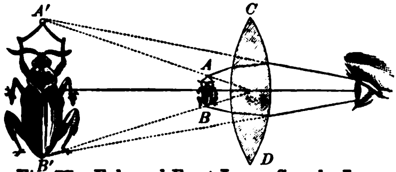


Fig. 77.—Enlarged Erect Image Seen by Lens.

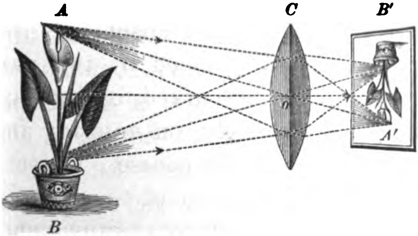


Fig. 78.—Inverted Image Formed by Lens.

If the object be placed further from the lens, as, for example, at *A B*, Fig. 78, then the rays of light from the object would, after passing through the lens, form on a screen an inverted image, *B′ A′*, smaller than the object.

If the object be placed, as it is in the magic-lantern, in the inverted position, shown at *B′ A′*, Fig. 78, nearer to the lens than the flower at *A B*, Fig. 78, but further from it than the beetle, *A B*, Fig. 77, then an enlarged, erect image would be formed on a screen placed at *A B*, as shown in Fig. 78.

188. The Human Eye.—Look into a person's eye, and you will see a whitish ball, in the middle of which is a round, colored portion. In the middle of the round, colored part you can see a small, round, dark hole. The colored portion of the eye is called the *iris;* the dark hole in the *iris* is called the *pupil.* It is through the pupil only that light enters the eye.

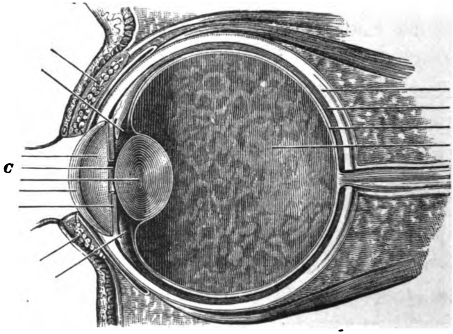


Fig. 79.—A Section of the Human Eye.

In Fig. 79 is shown the appearance the eye would present if cut vertically in two. The opening of the pupil is shown at *C.* Both in front of the pupil, and back of it, are a number of watery and jelly-like substances which act as lenses. When the light from any object placed in front of the eye, passes through these lenses, they form a small image which falls on the back of the eye, on a delicate screen called the *retina*. This retina consists of a number of very fine nerve-fibres. When the image falls on the retina, we experience the sensation of sight.

189. The Camera-Obscura.— The human eye acts like an instrument called the *camera-obscura*, by means

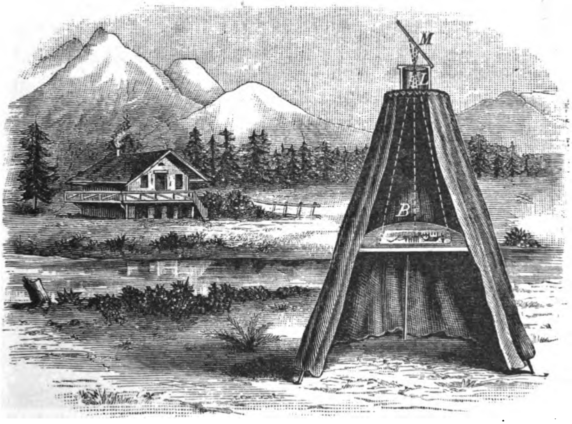


Fig. 80.— Camera-Obscura.

of which small images of distant objects are obtained. A lens, *L*, Fig. 80, is placed in the top of a darkened space. Rays of light from distant objects are thrown by means of a mirror, *M*, on the lens, *L*, and passing through the lens form a small image on a screen placed at *B*. This image, like that formed on the retina of the eye, is inverted, and smaller than the objects which cause it.

190. Color. The Dispersion of Light.

Experiment (82).—In the path of a beam of sunlight, entering a darkened room through a narrow slit cut in a card tacked over a hole in the shutter, place a prism in the position shown in Fig. 81. If no better prism can be obtained, a prismatic piece of glass from a gas chandelier will answer. Observe that not only will the direction of the beam be changed, but that there will be spread out on the wall opposite, a brightly colored band, *V R*, called a *spectrum*.

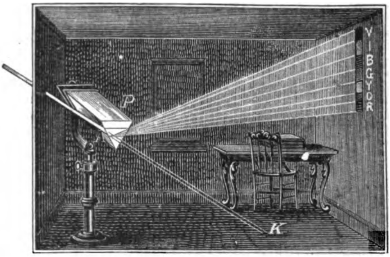


Fig. 81.—Formation of a Spectrum by a Prism.

Sunlight, and indeed nearly all light, contains in it a great number of different colors, and when the light passes through a prism, these colors are separated one from another. This process is called the *dispersion of light.*

We can see in the spectrum described in connection with Fig. 81 a great variety of colors. We distinguish, however, for the sake of simplicity, but seven, represented in Fig. 81 by their initial letters; viz., violet, indigo, blue, green, yellow, orange, and red.

191. The Cause of Color.—All the colors of the spectrum when rapidly mixed together will make a white color.

Experiment (83).—Cut a disc out of a piece of stiff paste-board, and paint on it, in the spaces shown in Fig. 82, seven colors, as near as can be obtained to those seen in solar spectrum or in the rainbow. Stick a pin through the centre of the disc, and whirl it rapidly around with the fingers. When it is turning fast enough, the disc, from the mingling of the different colors, will appear to be painted grayish white.

Experiment (84).— Remove some of the colors by fastening a piece of dark paper over them, and whirl the disc as before. Observe that the disc is now uniformly tinted with a color that will vary as different colors are covered by the dark paper.

If, therefore, any color be taken from the sun's light, the light which is left will appear colored.

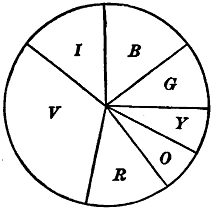


Fig. 82.—Color Disc.

When sunlight falls on any colored body, such as a piece of red cloth, all the colors but the red are absorbed, and this color being thrown off from the cloth it appears red. So in a blue cloth, only the blue is thrown off, and the rest of the colors are absorbed.

The color of a body, then, is caused by the light which falls on it. In the dark no body has color. A red body, illumined by light containing no red, will appear of a dark gray or black.

Experiment (85).— Roll a piece of lamp-wick into a loose ball, and soak it for a few moments in a very strong solution of salt in water. Then wringing most of the water from the wick, placing it in a saucer, and pouring some alcohol over it, set fire to the wick. It will burn with a pure yellow light. Observe now, that if different colored objects, such as zephyrs, cloths, or silks, be examined by means of this light, in an otherwise darkened room, they will all appear to have lost their color, except those which were yellow. Now bring a lighted candle near any of the colors, and, since the lighted candle gives off light of all colors, the color of the fabrics will again appear.

SYLLABUS.

If light coming from illumined objects enters a darkened room through a small opening, it will form, on a screen placed near the opening, an inverted image of the objects from which it came.

Bodies are always seen in the direction in which their light enters the eye.

An object placed in front of a looking-glass will appear to be as far back of the glass as it is really in front of it, because the direction of its light is changed by reflection from the glass.

The light from the extremities of an object, entering the pupil of the eye, forms an angle called the visual angle. The apparent size of an object depends on the visual angle under which it is seen. Any cause which alters the visual angle under which an object is seen, alters its apparent size.

A person looking at himself in a curved mirror, sees an enlarged image, because the light from his body is so changed in direction after reflection from the mirror, as to enter the eye under a different visual angle from that under which he would have seen himself if looking in a plane mirror.

If an object is looked at through a prism, its light on entering and leaving the prism will be changed in direction by refraction, so that the object will appear out of its real position.

Lenses are transparent pieces of glass bounded by two surfaces, both of which are generally curved, but one of which may be plane.

Objects seen through a lens may appear to the eye under a different visual angle than if the eye looked at them directly; therefore, their apparent size may be very different from their real size.

The light from visible objects enters the eye through a small, round opening, in the iris, or colored part of the eye, called the pupil; on passing through the lenses of the eye, this light forms a small image on a screen called the retina, and causes us to see.

In the camera-obscura, a lens forms a small image of distant objects on a screen placed below the lens.

When sunlight passes through a prism, the light is separated into a great number of different colored lights. The band of colors so formed is called a spectrum.

All the colors of the spectrum, when mixed together, form a white light. If any color be taken from the spectrum, the remaining colors mixed together will no longer form a white.

When sunlight falls on a red cloth, all the colors but the red are absorbed, and the red only thrown off. The cloth therefore appears red.

QUESTIONS FOR REVIEW.

Explain why the images of objects formed by light entering a small opening in a darkened room, are seen upside down.

In what direction will any visible object appear?

Why does an object seen in a looking-glass appear out of its real position? How far back of a looking-glass will an object placed in front of it appear?

Describe a method of looking through a brick.

Define visual angle. What effect has the visual angle under which an object is seen, on the apparent size of the object?

Why does a person looking at himself in a curved mirror, see a greatly enlarged image?

Can a curved mirror form an inverted image of an object placed in front of it?

How must a prism be held so that an object viewed through it shall appear above its real position?

How must the prism be held so that an object viewed through it shall appear below its real position?

Define lens. Why will objects seen through lenses often appear of different size than their real size?

What name is given to the round, colored part of the eye? What name is given to the opening in the colored part? On what part of the eye do the images formed by the lenses of the eye fall?

Describe the operation of the camera-obscura. In what respect is it like the human eye?

What is meant by the dispersion of light?

Define spectrum. What colors are very prominent in the spectrum?

What is the cause of color? Why does a red body appear red? Would a red body appear red if illumined by pure yellow light? Describe an experiment proving this.

CHAPTER XIX.

ELECTRICAL CHARGE, OR ELECTRICITY OF HIGH TENSION.

192. The Nature of Electricity.—But little is known as to the real nature of electricity. It is probably caused by a swinging movement of the atoms. It is, however, certainly a form of energy, and all other forms of energy can readily be converted into it.

193. Varieties of Electrical Energy.—Electricity manifests its presence in a variety of ways; these, however, may all be arranged under two heads; viz.,

1st. *As a charge.*
2d. *As a current.*

194. Electrical Charge.—If a stick of sealing-wax be rubbed briskly against a cloth coat, or a piece of fur, the wax will acquire the property of attracting and repelling light bodies brought near it. The wax has been electrified by the rubbing, and has received what is known as *an electrical charge.* A part of the energy of motion of the arm has been changed into electrical energy.

Bodies may receive an electrical charge in a variety of ways, the commonest of which is friction. Under certain conditions an electrical charge possesses the power of leaping through distances in order to overcome obstacles placed in its path. It is then called *electricity of high tension.* **Electricity reaches its highest** tension in the lightning-stroke.

195. Electrical Current.—If an electrified body be held in the hand, its electricity will flow into the ground. In this way a momentary *current* of electricity is caused.

If a piece of zinc and copper, separated a few inches at one end, but connected at the other by a wire, be dipped into weak sulphuric acid, so that the ends connected with the wire be out of the liquid, a current of electricity will flow through the liquid between the zinc and copper, and, out of the liquid, through the connecting wire, as long as any of the zinc remains for the acid liquid to dissolve. As a result of this current, the wire acquires, besides other properties, that of attracting or repelling bodies called magnets.

196. Effects of an Electrical Charge.

Experiment (86).— Attach a ball made from the pith of the elder, though any other very light body will answer, to a silk thread. and tie the thread to any suitable support. Now electrify a warm dry, hard-rubber comb, or ruler, by briskly rubbing it against the coat, or against a piece of cat's fur, and hold the rubber near the ball. Observe that the ball is attracted to the rubber, as shown in Fig. 83, at *A*.

Experiment (87).— Touch the pith-ball with the rubber, and observe that the ball is now driven away or repelled as shown at B.

Experiment (88).— Electrify as before and move the rubber near the face. Observe that a creeping sensation is experienced as if cobwebs were drawn over the face.

Experiment (89).— If the air be dry, observe that if the comb, when electrified, be held, in a dark room, near the knuckles, faint sparks pass to the knuckles, and a faint crackling sound is heard.

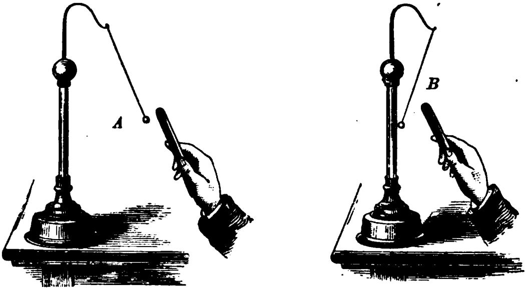


Fig. 83.— Electrical Attractions and Repulsions.

197. Positive and Negative Electricity.— If a glass rod be electrified by rubbing it with a piece of silk, it will, when held near the pith-ball, attract it as shown at *A*; but if it be touched to the ball, it will then repel it.

If a piece of sealing-wax, rubbed with flannel, be brought near the ball when it is hanging quietly, it will also be attracted, and if it be touched to it, will repel it. But, if while the ball is repelled by the glass, the sealing-wax be brought near, the ball will be attracted; or, if while the ball is repelled by the wax, the glass be brought near, the ball will be attracted.

Very many different substances are electrified by friction; but they all act either like the glass, or like the sealing-wax. There are, therefore, but two kinds of electrical charge, or excitement; viz., one like that seen in glass rubbed with silk, and called *positive electricity*, and one like that in sealing-wax rubbed with flannel, and called *negative electricity.*

When a body is electrified by rubbing, the rubber always takes one kind of electrical excitement, and the thing rubbed the other kind.

198. Laws of Electrical Attractions and Repulsions.— *Bodies charged with the same kind of electricity repel one another; those charged with different kinds, attract one another.* That is, a body charged with positive repels another body charged with positive, or a body charged with negative repels another body charged with negative; but a body charged with positive, or negative, attracts a body charged with negative, or positive.

199. An Electroscope. —An *electroscope* is used to determine whether bodies are electrified, and to find with what kind of electricity they are charged. It consists, as shown in Fig. 84, of two thin leaves of gold, *n n*, hung inside a dry jar by a metal wire, which terminates in a ball, *C*.

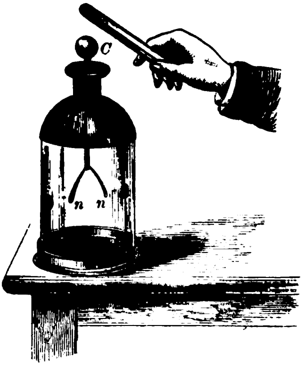


Fig. 84.— An Electroscope.

If an electrified body be brought near *C*, the leaves fly apart. To determine the kind of electricity a body has, cause the leaves to diverge by touching *C*, with a body whose electrical charge is known, such as glass rubbed with silk, that is, positive. Now bring near it the body whose electricity is unknown. If the leaves diverge still further, its charge is positive, or the same as that the leaves possessed. If the leaves, however, are attracted, the charge is negative.

Experiment (90).—Cut two discs of gilt paper, *a b*, as large as quarter dollars; connect them with *linen* or *cotton* threads as shown. Stick a wire through a cork of a wide-mouthed bottle, and tie the threads to the end of the wire, leaving the discs hanging with about ¼ inch of thread. Solder a smooth button to the end of the wire, and put the cork in the bottle, so that the pieces of paper shall be inside the bottle, as shown in Fig. 85, first, however, being sure that the bottle is *perfectly dry* by heating it on a warm stove. The cork also must be perfectly dry. Run sealing-wax over the top of the cork, so as to prevent any moist air from afterwards getting into the bottle. This apparatus will now serve as a very delicate electroscope.

Fig. 85.
An Electroscope.

200. Conductors of Electricity.

Experiment (91).—Place the electroscope, shown in Fig. 85, on a table, and wrap one end of a wire fifteen or twenty feet long around the button, *C*. Tie a silk thread to the other end, and have it held so that the wire nowhere touches anything on the floor or table. Now electrify any body and touch it to the end of the wire. Observe that the leaves instantly diverge, showing that the electricity has passed from the body through the wire.

Experiment (92).—Try the same experiment, replacing the wire by a silk thread. Observe that no electricity flows through the silk.

Bodies like the wire, that allow electricity to flow readily through them, are said to be good *conductors of electricity.*

Bodies like the silk, that will not allow electricity to flow through them, are said to be poor *conductors* of electricity. A body resting on, or supported by a poor conductor is said to be *insulated.*

The metals, charcoal, graphite or the so called black-lead in lead-pencils, water, the human body, and linen or cotton thread are good conductors.

Dry air, India-rubber, silk, glass, wax, and hard rubber are very poor conductors.

All experiments in electricity of high tension should be tried during clear, dry weather, since moist air conducts the electricity away as soon as it is produced, and so spoils the experiment.

201. Electrical Machines. The Electrophorus.—One of the simplest forms of electrical machines is the electrophorus. It consists of a disc of hard rubber or rosin, *B*, and a metallic disc, *A*, which is insulated by a glass rod, *C*. Charge the disc, *B*, by rubbing it with cat's fur; then, holding *C*, as shown in Fig. 86, place the plate, *A*, on *B*, and touch it with the other hand. Now remove *A*, holding it by the glass rod, and the plate, *A*, will give an electrical

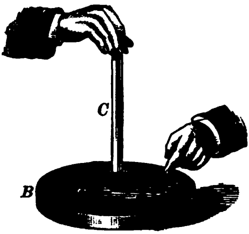


Fig. 86.
The Electrophorus (charging).

Fig. 87.
The Electrophorus (discharging).

spark to anything brought near it. When *B* is once charged by rubbing, any number of sparks can be taken from *A* by placing it each time as shown in Fig. 86, and touching with the hand before raising it.

202. The Plate Electrical Machine.—A more convenient form of machine is *the plate electrical machine*, shown in Fig. 88. A plate, *A*, of glass, is supported so as to be readily turned on the axis, *B*, by the handle, *C*. Stout springs firmly press two pieces of chamois leather, covered with a substance called amalgam, against the glass plate. A metallic conductor, *E*, is connected by metal with the rubber, and a larger conductor, *O*, is connected with a set of needle-points, *F*, placed near the plate.

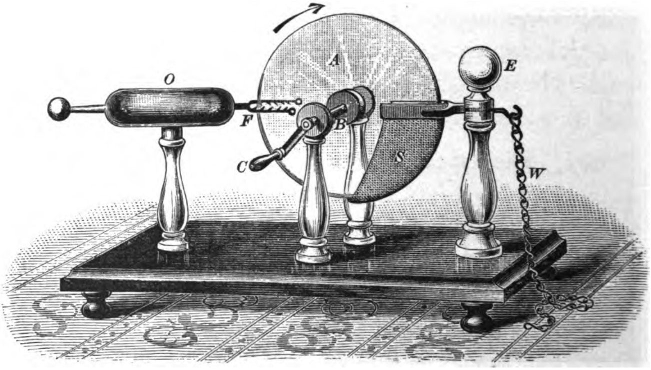


Fig. 88.—Plate Electrical Machine.

When the plate is turned, the friction of the rubber against the plate electrifies the glass; the negative electricity is collected at *E*, and the positive at *O*. By connecting *E* to the ground by the metallic chain, *W*, the positive electricity collects more rapidly in *O*. An apron of silk, *S*, placed as shown, loosely covers a part of the plate.

203. Effects of the Electric Discharge.—An electric discharge from a large surface passed into the human body gives it a sudden shock.

During the discharge of an electrified body, a bright spark is seen.

A powerful discharge sent through thin wire will heat and even volatilize the metal.

A powerful discharge passed through a poor conductor produces violent fractures or tearings.

204. Lightning.—The atmosphere almost always has some free electricity in it. The moisture in clouds enables them to collect this free electricity. When a cloud thus charged comes sufficiently near the earth, it is discharged into the nearest object. The flash is called *lightning*. An electrified cloud sometimes discharges into another cloud.

Thunder is caused by the violent disturbance of the air occasioned by electricity passing through it, or by the rapid formation and condensation of vapor, due to the passage of electricity through drops of rain.

205. Lightning-Rods.—Lightning-rods, first proposed by Franklin, consist of stout rods of iron, or, preferably, of copper, attached to the outside of the building to be protected, and extending some little distance above its highest point. The upper end of the rod should be pointed, and its lower end should extend *deep into the ground*, until it meets *permanently* damp earth, or some conductor of electricity. If underground water- or gas-pipes are in the neighborhood, it is well to connect the rod to them. If the roof of the building be of metal, such as tin or copper, *it should be connected with the rod.* The rod should be of *sufficient thickness* to conduct to the earth, without being melted, the heaviest discharge that may strike the building.

A solid rod is to be preferred, as an electrical current passes through the whole mass of the conductor, and not only over the surface. A lightning-rod, not well electrically connected with the earth, is more a source of danger than of protection.

206. Some Simple Experiments in Electricity.

Experiment (93).—Suspend a ruler by a cotton string so that the ruler will hang horizontally. Bring an electrified body near the ruler, and observe that it will be attracted. Try the same thing with a long brush-handle.

Experiment (94).—Get a smooth pine board larger than a sheet of letter-paper. Heat the board and sheet of paper before a fire. Then place the paper on the board, and stroke it briskly with a piece of India-rubber, such as is used for erasing lead-pencil marks. The paper will become strongly electrified. Now lifting the paper from the board by one of its edges, bring it near the wall, and observe that it will be at once attracted to the wall, and will cling to it.

Experiment (95).—Electrify the paper as before, and, while it is on the board, cut it into strips. Lift the strips at one end from the board. Observe that their lower ends will be repelled, and will stand out from one another in a very amusing manner.

Experiment (96).—Electrify a piece of paper as before. Remove it from the board, and lay a pith-ball on it. Observe that the ball will either be at once thrown off the paper, or will first run to the lower side of the paper, and will then be thrown off from it.

Experiment (97).—Place a metal waiter on top a dry glass goblet. Electrify the paper and place it on the waiter. Apply the knuckle to the edge of the waiter, and observe that a spark passes to it. Remove the paper by the edge, and another spark can be taken from the waiter.

Experiment (98).—Support a clean, dry pane of window-glass, one inch or so above the surface of a table, by resting the edges on sticks of wood. Place three or four pith-balls under the glass, and rub the top of the glass briskly with a piece of silk, or cat-skin. Observe that the balls move about in a curious manner, and that some will probably stick to the glass. Now stop rubbing, and hold the finger near the glass, above the balls, and they will at once fall.

SYLLABUS.

Electricity is a form of energy. All other forms of energy can readily be converted into electrical energy. Electricity is probably caused by a swinging movement of the atoms.

Electrical energy manifests its presence either as an electrical charge, or as an electrical current.

A piece of hard rubber, when rubbed briskly against a coat or piece of cat-skin, becomes electrified, or receives an electrical charge. If while electrified it be held in the hand, its electricity will flow through the body into the ground as an electrical current.

Energy may be changed into electrical energy in a great variety of ways. Electrical charge is most conveniently obtained by means of friction. Electrical current is most conveniently obtained by the chemical action of acids, or other substances, on metals.

A body containing an electrical charge, attracts or repels easily moved bodies brought near it; if moved close to the face, it will cause a creeping sensation; if brought near the knuckles, a faint crackling will be heard, and in the dark, a bluish spark seen.

There are two kinds of electrical charge; viz., positive, or like that given to glass by rubbing it with silk; and negative, or like that given to sealing-wax by rubbing it with flannel.

Bodies charged with the same kind of electricity repel one another. Bodies charged with different kinds attract one another.

An electroscope consists of two gold leaves, or leaves of any conducting material, hung so as to move readily towards or from one another. When electrified the leaves move apart.

Conductors of electricity are substances that allow electricity to flow readily through them. Some substances, such as metals and the human body, are very good conductors; while others, such as glass, dry air, or hard rubber, are very poor conductors.

Lightning is caused by an electrical charge passing from a cloud to the ground or to a neighboring cloud. Thunder is the sound caused by a violent disturbance of the air produced by the lightning.

Lightning-rods protect buildings on which they are placed, by allowing the electricity to flow quietly down them into the earth.

QUESTIONS FOR REVIEW.

Is electricity a kind of matter or a form of energy? What is probably the cause of electricity?

In what two ways does electrical energy manifest itself?

Define electrical charge. Define electrical current. How may an electrical charge be obtained? How may an electrical current be obtained?

What is positive electricity? What is negative electricity?

State the law of electrical attractions and repulsions.

What is an electroscope? How is it used to determine the kind of electricity a body possesses?

What is meant by a good conductor of electricity? What is meant by a poor conductor? When is a body said to be insulated?

Describe the construction and operation of an electrophorus.

Describe the plate electrical machine.

State all the effects produced by an electric discharge.

How is the free electricity of the air collected?

What is the cause of lightning? By what is thunder caused?

Describe the construction of a lightning-rod. What precautions should be taken in erecting the rod? How does a lightning-rod protect a building on which it is placed?

Describe any simple experiment in electricity.

CHAPTER XX.

EFFECTS PRODUCED BY AN ELECTRICAL CURRENT.

207. Electrical Currents.— There are various ways in which electrical currents may be obtained, one of the most convenient of which is by chemical action. Electricity produced by chemical action is often called *voltaic electricity*, from Volta, the discoverer of the first electrical battery, or cell. The apparatus for producing this kind of electricity is called a voltaic cell.

208. The Simple Voltaic Cell.— A simple voltaic cell consists of two plates of different metals, dipped into any liquid that can act chemically on one of them, and connected outside the liquid by a wire of some good conducting material.

There are a great variety of voltaic batteries, but in each of them there are but two different metals. In some there are two different liquids, one for each metal.

A very simple voltaic cell is shown in Fig. 89. It consists of a plate, *Z*, of zinc, placed in a cup, *B*, near a plate, *C*, of copper. The cup is partly filled with a mixture of sulphuric acid and water. When the cell is in action, the copper and zinc are connected outside the liquid by a conducting wire, *M*, as shown.

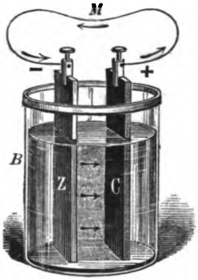


Fig. 89.
A Simple Voltaic Cell.

209. The Voltaic Circuit.—When the voltaic cell is arranged as shown in Fig. 89, an electrical current flows constantly through the liquid from the zinc to the copper, and through the conducting wire, outside the liquid, from the copper to the zinc. The arrows show the direction of the current. The current, it will be noticed, returns to where it started, and is therefore called the *voltaic circuit.*

We *make*, *complete*, or *close* the voltaic circuit when we connect the plates outside the liquid by a wire. We *break*, or *open* the circuit, when we disconnect the plates by breaking or separating the conducting wire at any point. *No current flows when the circuit is broken. The current immediately begins to flow when the circuit is made or completed.* These effects occur though the conducting wire, connecting the plates, be hundreds or even thousands of miles in length.

210. Effects Produced by an Electrical Current. The passage of an electrical current, through a wire or other conductor, produces in the wire or other conductor a number of effects, the principal of which are as follows; viz.:

1st. *Thermal effects.*—The wire becomes heated.

2d. *Luminous effects.*—If the wire be broken at any point, a brilliant flash of light appears.

3d. *Physiological effects.*—An electrical current, sent through the body of an animal, produces involuntary movements of the muscles.

4th. *Chemical Effects.*—An electrical current, sent through a compound liquid conductor, causes a decomposition and recombination of its constituent elements.

5th. *Magnetic Effects.*—All conductors conveying electrical currents are thereby rendered magnetic, that is, acquire the property of attracting or repelling bodies called magnets.

211. Thermal Effects.—Whenever an electrical current passes through a conductor, it heats the conductor. If the conductor be stout, this heat is not very perceptible unless the current be great; but if the conductor be thin and of not very good conducting material, it will be heated so high as to give off light, and may even be volatilized.

212. Luminous Effects. The Electric Light.—If a wire or other conductor conveying a powerful electric current be broken at any point, there will be seen at this point a brilliant flash of light. If the broken ends of the wire be connected to two sticks of hard carbon or charcoal, and the carbon-points be pressed together and then separated a short distance, and kept that distance apart, a brilliant arc of flame, called the voltaic arc, will be maintained between them. This flame is intensely hot, and heats the carbon-points so high as to gradually volatilize them.

It emits a light but little inferior in intensity to that of the sun, and is therefore of great value for purposes of artificial illumination. When used for the electric light, the carbon-points are made of very hard material, so that their consumption shall not be too rapid. As the carbon-points are gradually consumed, they are slowly fed or moved towards each other by any suitable means.

The carbon-points are too brilliant to examine directly, but if an image of them be thrown on a screen, by means of a lens, an appearance will be seen like that shown in Fig. 90. The current passes from the upper to the lower carbon. The upper carbon is hollowed out by the passage of the current, while the lower one is pointed. The round globules, seen on the carbons, are melted drops of impurities in the carbons.

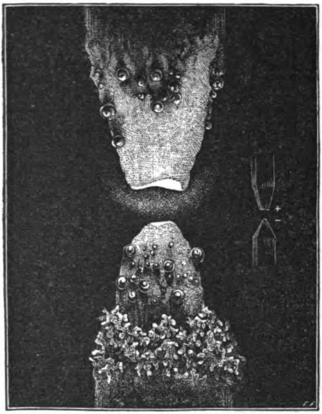


Fig. 90.
An Image of the Carbon-Points.

The *Aurora Borealis*, or Northern Light, is caused by electricity passing through the upper regions of the atmosphere.

213. Physiological Effects.—An electrical current passed through the body of an animal recently killed produces convulsive movements of its muscles; sent through a live body, it causes various physiological actions favorable to the cure of certain diseases. *Electricity, however, as a curative agent, may do more harm than good, and should never be employed except by a skilful and intelligent physician.*

214. Chemical Effects.—An electric current passed through a metallic solution decomposes the solution, and deposits the metal on that conductor which carries the current out of the solution.

If, for example, a bright, clean piece of iron or other metal be connected to the wire leading from the zinc plate of the voltaic cell, shown in Fig. 89, be dipped into a solution of bluestone or copper sulphate, and the wire connected to the copper plate be connected to a second copper plate, and also dipped into the solution of copper sulphate so as to be near the piece of iron but not to touch it, the passage of the current through the solution of copper will cause the copper to be deposited in a strong, bright, adherent film to the iron or other metal.

This process, by means of which one metal can be deposited on the surface of another, is called *electro-plating*, or sometimes *electro-metallurgy*. By its means, silver and gold are deposited on the surfaces of cheaper metals.

215. Magnetic Effects.—Any conductor, through which an electric current is passing, becomes a magnet, and continues a magnet until the current ceases to pass. *Magnets* are bodies that possess the power of attracting iron and causing it to cling to them. They also possess the property of attracting or repelling other magnets.

If a strong electrical current be passed through a conductor, such as a copper wire, the wire will become magnetic and acquire the property of attracting small filings of iron. If a long wire, covered with cotton or some other insulating material, be wrapped closely around a lead-pencil in four or five layers, and the pencil then slipped out and a rod of soft iron of the same thickness put in its place, a much weaker current passed through the wire will cause the iron bar or rod to become strongly magnetic, so that it will hold a tack or an iron nail to it. If the rod be bent in the form of the letter U, so as not to disturb the coil of wire on it, and the current passed through as before, the iron rod, or *core*, as it is generally called, will now hold or draw to it still heavier pieces of iron.

If the core be made of soft iron, it will instantly become a magnet when the current is caused to flow through the coil of insulated wire surrounding it, but will instantly lose its magnetism when the current in the coil ceases.

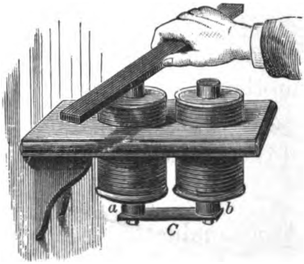


Fig. 91.—An Electro-Magnet.

Instead of bending the iron core, it may be made in two pieces, *a*, *b*, as shown in Fig. 91; in this case the lower ends of the bars are connected by a bar, *C*, of soft iron.

If, while the current is passing through the coils of insulated wire on *a* and *b*, a bar of hardened steel, *D*, be touched to *a* or *b*, it will be made a magnet, and will retain its magnetism after its removal. But if *D* had been a bar of soft iron, it would only become a magnet while touching *a* or *b*, and would lose its magnetism as soon as it was removed.

A magnet, such as that shown in Fig, 91, which is produced by the passage of an electric current, is called *an electro-magnet.* A bar of steel which has been magnetized is called a *permanent magnet*, because it retains or keeps its magnetism for a long time.

216. A Magnetic Needle.—If a permanent steel magnet, *N S*, be supported, as shown in Fig. 92, at its centre of gravity, so as to be free to move, it will, in most parts of the earth, come to rest with its length in a nearly north and south direction. If the bar, *N S*, be removed from its support and rolled in iron filings, the filings will collect in greatest amount near the ends, *N* and *S*, while the middle will be nearly free. The points, *N* and *S*, where the magnetism manifests itself most energetically, are called the poles. In this country the end of the magnet, which points towards the north pole of the earth, is called the *north pole;* the other end is called the *south pole.*

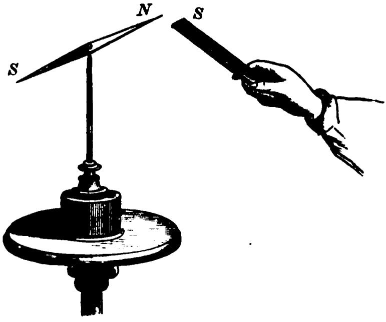


Fig. 92.—A Magnetic Needle.

217. Magnetic Attractions and Repulsions.—If the north pole of a magnet be brought near the south pole of a magnetic needle, as shown in Fig. 92, they attract each other; but if the north pole be brought near the north pole of the needle, they repel each other. We generally express these facts as follows; viz.:

Like magnetic poles repel, and unlike poles attract; that is, north attracts south, or south north; but north repels north, and south repels south. This, it will be remembered, is the same as the attractions and repulsions of bodies containing an electrical charge.

Experiment (99).—Place a steel magnet on a table and sprinkle iron filings over the magnet. Remove the magnet from the table and gently shake off the filings that do not cling to the magnet. Observe that the filings have collected in greatest amount near the ends or poles, and that very little or none remain on the middle.

Experiment (100).—Touch one end of a steel pen to either of the poles of the magnet and the other end to the other pole. Lay the pen on a chip of wood, and float it on a water surface, in a plate or saucer. Observe that when the steel magnet is held near the pen, it is driven away or drawn towards it, according to the pole that is brought near it.

Experiment (101).—Place the magnet on a table, and lay over it a piece of smooth window-glass or a sheet of stiff paper stretched in a frame. Sprinkle some fine iron filings on the glass or paper, and then tap on the edge of the paper or glass gently with the fingers. Observe that the filings will be arranged in beautiful curved lines by the influence of the magnet.

Experiment (102).—Place the middle of a steel knitting-needle on one of the poles of the steel magnet, and draw the needle off the magnet in the direction of its length. Replace the needle as before, and again draw it off. Do this several times. Then touch the middle of the needle to the other pole, and draw it off so that the other half of the needle shall be rubbed against this pole. Repeat this motion as before, and the needle will become thoroughly magnetized. Suspend the needle by a piece of cotton so that it will hang in a horizontal position. Observe that it will behave like a magnetic needle.

Experiment (103).—Prepare a second needle like the first, and, suspending it, ascertain its poles. Then try the effects produced by attraction and repulsion.

218. Cause of the Magnetic Needle Pointing towards the North.—The magnetic needle points to the north pole of the earth for the same reason that the opposite poles of magnets point to each other, if they are sufficiently near and free to move. *The earth acts as a huge magnet, with its magnetic poles in the neighborhood of the poles of the earth*, and the magnetic needle points towards these poles on account of their attraction.

We do not know the cause of the earth's magnetism, but think that it is due to electrical currents passing around the earth.

The magnetic needle does not point in all, or even in most places to the exact geographical north, but to the east or west of the true north. This deviation is called the *variation* or *declination* of the needle, and, in many parts of the earth, causes the magnetic needle to vary very considerably from the true north.

219. Applications of Electro-Magnets.—There are numerous applications made of the fact that an electro-magnet is magnetic only while the current is passing through its coils.

In the *electro-magnetic telegraph* a bar of soft iron, forming the core of an electro-magnet, is magnetized and demagnetized by making and breaking the circuit of the coil of wire wrapped around its core.

In the Morse system of telegraphy, so named from its inventor, a *voltaic battery*, two *keys*, and two *Morse instruments* are connected in one circuit; that is, they are placed so that the current from the battery may flow through the keys and instruments, and then return to the battery.

The key is simply an arrangement by means of which the circuit is easily made and broken.

The Morse instrument consists of a bar, *B*, pivoted at *C*, and having attached to one end a bar of soft iron, *A B′*, called an *armature*, so placed as to be directly over the poles of an electro-magnet, *M*; at the other end of the bar, *B*, is a steel point, *P*, which presses against a long strip of paper drawn lightly over the point by clock-work or other suitable means.

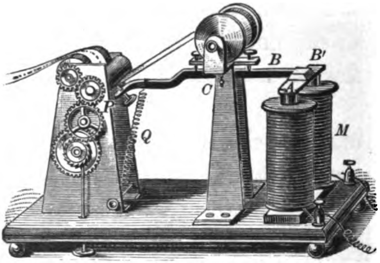


Fig. 93.—A Morse Receiving Instrument.

In the same circuit, but at a distant station, is placed another key and Morse instrument similar to those just described. When the circuit is made by the keys at both stations being pressed down, the electricity from the battery flows through the Morse instrument, through the telegraph-wire stretched over the telegraph-poles, to the distant station, through the key and Morse instrument at the distant station, and back again, practically, through the earth to the battery.

If the operator at the distant station should depress his key when the circuit is broken, he thereby closes it, and *M*, becoming magnetic, pulls down the armature, *A B′*, causing the point, *P*, to indent the paper. If he keeps the key down for some little while, the paper will be drawn over the point, and a dash or long mark made on it; but if the key is only kept down for a moment, then but a dot will be given to the paper. When the operator raises the key, the circuit is broken, *M* ceases to be a magnet, and the point is pulled away from the paper by a spring, *Q*.

By adopting a system of dots and dashes to represent the letters of the alphabet, communications can be carried on very rapidly between distant places.

220. The Morse Alphabet.—In the following table are given the combinations of dots and dashes employed in the Morse system to represent the letters of the alphabet.

a	·—	j	—·—·	s	···
b	—···	k	—·—	t	—
c	·· ·	l	——	u	··—
d	—··	m	——	v	···—
e	·	n	—·	w	·——
f	·—·	o	· ·	x	·—··
g	——·	p	·····	y	·· ··
h	····	q	··—·	z	··· ·
i	··	r	· ··	&	· ···

To avoid the running of one letter into another, such, for example, as *i* · · and *e* ·, which might be mistaken for · · · *s*, a space is left between successive letters longer than that between any of the separate dots of any single letter, and a still longer space is left between words.

It will be noticed that two dots, an interval, and one dot stand for *c*, while three dots stand for *s*; *i* is represented by two dots, while *o* is represented by a dot, an interval, and a dot. Similar differences are noticed in the signs for *h* and *y*, *c* and *r*, *z* and *&*. These differences are more marked when only the sounds are regarded, and, indeed, most telegraphy by the Morse system is effected by means of the sounds, as already explained.

The numerals are represented as follows:

1 .—...
2 ..—..
3 ...—.
4 ....—
5 — — —
6 ......
7 — —..
8 —....
9 —..—
0 ——

221. Magneto-Electric Currents.—If a coil of wire, connected in a closed circuit, be rapidly moved near a magnet, or the magnet be rapidly moved near the coil, an electrical current will be developed in the coil. This current flows through the coil in one direction, while the coil and the magnet are approaching each other, and in the opposite direction when they are moving away from each other. When so desired, these currents can be caused to flow in a constant direction. Electrical currents, produced in this way by the motion of a magnet, are called *magneto-electric currents*.

Powerful magneto-electric currents can more readily be obtained than voltaic currents. They are also much cheaper, and are therefore always employed, in preference to voltaic currents, for the purposes of electric lighting.

The machines by means of which they are obtained are called dynamo-electric machines, of which there are many forms. One of them, shown in Fig. 94, is known as the Gramme machine, from the name of its inventor. A coil, *B*, of insulated wire, wrapped in the form of a ring, is rapidly rotated by means of a steam-engine, or other source of power, between the poles, *N* and *S*, of powerful electro-magnets, ***M M***, and ***M′ M′***. The direction of the current is kept constant by means of an arrangement at *C*, called a *commutator*.

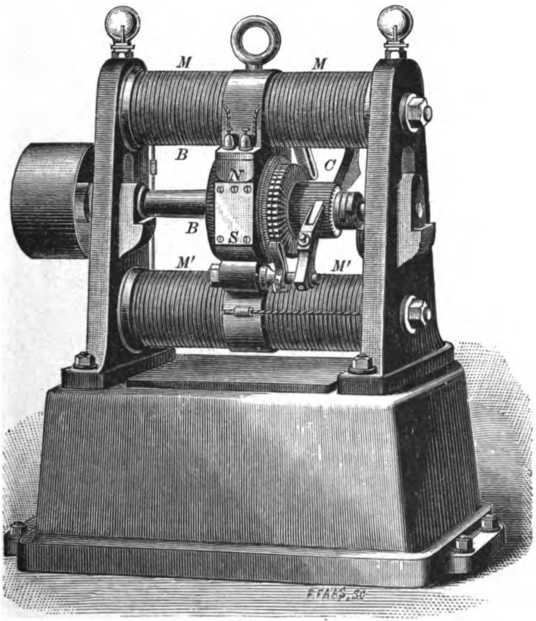


Fig. 94.—The Gramme Dynamo-Electric Machine.

SYLLABUS.

Electrical currents obtained by means of chemical action are called voltaic currents.

A simple voltaic cell consists of two plates of different metals plunged into a liquid that can act chemically on one of the metals, and connected outside the liquid by a wire of some conducting material.

The electricity produced by a voltaic battery flows through the liquid from one of the metals to the other, and out of the liquid through the conducting wire, and so back again to the battery. This path of the current is called the voltaic circuit, or simply an electric circuit.

The electric circuit flows all the same if the conducting wire connecting the two plates of metal be miles in length, or if any other conducting substance be used in its place.

The current from the battery flows only while the circuit is made; it at once ceases to flow when the circuit is broken.

An electrical current flowing through a conductor produces various effects. These may be classed as, 1st, thermal effects; 2d, luminous effects; 3d, physiological effects; 4th, chemical effects; and, 5th, magnetic effects.

If a conductor conveying an electrical current be broken at any point, a bright flash of light is seen at the break. If the broken ends be connected to pieces of hard carbon, and these pressed firmly together and again separated, an intensely bright arc of flame, called the voltaic arc, is produced.

The voltaic arc is intensely hot and bright, and is used for the purpose of obtaining artificial light.

Electricity may act as a curative agent, but, unless employed by a skilful and intelligent physician, may do more harm than good.

An electric current passed through a solution of a metal will decompose the solution and deposit the metal in a bright, closely-adherent film on any metallic article dipped into the solution. This process is called electro-plating or electro-metallurgy.

All conductors through which electric currents are passing are thereby rendered magnetic.

The magnetizing effects of an electric current are made more powerful by sending the current through a coil of insulated wire surrounding a bar or core of soft iron. Such an arrangement is called an electro-magnet.

A bar of hard steel, touched to the poles of an electro-magnet, becomes permanently magnetized.

A magnetic needle consists of a magnetized bar of steel so supported at its centre of gravity as to be free to move. Such a bar comes to rest with its length pointing nearly north and south.

The ends of a magnetized bar, where the magnetic force is most manifest, are called poles. That end of the magnetic needle which points to the north pole of the earth is called the north pole of the needle; the other end is called the south pole.

The magnetic needle points nearly due north and south because the whole earth acts as a huge magnet, with its magnetic poles in the neighborhood of the geographical poles.

Like magnetic poles repel; unlike magnetic poles attract.

In the electro-magnetic telegraph, signals are sent from one station to another by means of an electric current. When a key at a distant station is depressed, so as to make the circuit, or, allow the current to flow over the line, an armature of an electro-magnet is pulled towards the magnet and makes a peculiar mark or sound.

Magneto-electric currents are caused by the movements of coils of insulated wire, or of magnets, towards and from one another.

QUESTIONS FOR REVIEW.

Define voltaic electricity. Why is it so named?

Describe the simple voltaic cell.

What is meant by a voltaic circuit? What is meant by making or completing the voltaic circuit? What is meant by breaking or opening the voltaic circuit?

Name all the effects produced by the passage of an electrical current.

Describe the thermal effects.

How are the luminous effects obtained? What is the cause of the Aurora Borealis? What is meant by a voltaic arc? For what purpose is the voltaic arc employed? Why must the carbons used for the electric light be gradually moved towards each other?

Describe the physiological effects of an electric current.

What chemical effects are produced by the voltaic current?

Describe the process of electro-plating a bar of iron or other metal with copper.

What magnetic effects are produced by the passage of an electric current?

Describe the construction of an electro-magnet.

How are permanent magnets produced? How do permanent magnets differ from electro-magnets?

What is a magnetic needle? Define poles of a magnet. Which pole of a magnet is called the north pole? Which is called the south pole?

State the law of magnetic attractions and repulsions. Why does the magnetic needle point nearly to the geographical north?

What is believed to be the cause of the earth's magnetism?

Define declination or variation of the magnetic needle.

Describe the construction of a Morse telegraphic apparatus.

Describe the method used for transmitting signals in the Morse system of electro-magnetic telegraphy. How are these signals made to represent letters and figures?

How are magneto-electric currents obtained? For what purposes are these currents employed?

QUESTIONS FOR EXAMINATION.

Chapter I.—Matter.

1. WHY must a stone, when thrown into water, displace a bulk of water equal to its own bulk? What name is given to this property?

2. How can you prove that water is a kind of matter?

3. Define substance; body; phenomenon; natural law, and energy.

4. Mention some properties that enable us to readily distinguish gold from marble.

5. Define physical change. Give an example of a physical change.

6. Define chemical change. Give an example of a chemical change.

7. In what manner only can natural laws be discovered?

8. Distinguish between natural philosophy and chemistry.

9. Explain by an example what you understand by the words, cause and effect, as applied to natural phenomena.

10. What is the cause of all natural phenomena?

Chapter II.—The Properties of Matter.

1. Define magnitude or extension. Have all kinds of matter magnitude or extension?

2. How many metres are there in one English mile?

3. Describe any experiment illustrating the impenetrability of matter.

4. State any instance of the extreme divisibility of matter.

5. Define atom; molecule. Which is the smaller, the atom or the molecule?

6. Do the atoms or the molecules touch one another in any kind of matter? What are pores?

7. Describe any experiment by means of which the compressibility of air may be shown.

8. Distinguish between the compression and the contraction of air.

9. When matter is compressed, is it the size of the atoms or molecules, or of the spaces between them, that change?

10. Describe any experiment by means of which the expansibility of air may be shown.

Chapter III.—Inertia.

1. Explain what is meant by the inertia of a body.

2. Describe any experiment by which the inertia of a heavy book may be shown.

3. A passenger standing upright in a coach, and facing the horses, is thrown down by the sudden starting of the coach; will he be thrown forwards or backwards? Why?

4. Describe an experiment with a tumbler of water illustrating inertia.

5. Do living bodies possess inertia? How can this be proved?

6. Define fluid resistances.

7. Explain the causes of friction.

8. What must be done to a body at rest before it can begin to move, or to a body in motion before it can come to rest?

9. Why should "doubling" aid a flying hare in escaping from a pursuing hound?

10. How may the friction between surfaces be decreased?

Chapter IV.—The Three Conditions of Matter.

1. When ice melts, or when water passes off as vapor, is it the size of the molecules that changes or the distance between them?

2. What name is given to the force that causes the ice to melt or the water to evaporate?

3. Define molecular attraction; molecular repulsion.

4. What is meant by solid substances?

5. Why is it easier to tear a piece of pasteboard than a piece of equally thick sheet-iron?

6. What is meant by fluid substances? What two kinds of fluid substances are there?

7. Why have liquid substances no shape of their own?

8. Why are some liquids viscid and others mobile?

9. What is meant by gaseous substances?

10. In which are the molecules the farthest apart, in solids, in liquids, or in gases?

Chapter V.—Force and Motion.

1. Define force. Name some different varieties of force.

2. How does the direction in which a force acts affect the direction of the motion it causes?

3. What effect has the point at which a force acts on the kind of motion it causes?

4. What effect is produced on the motion of a body by the intensity of the force which causes the motion?

5. Define mass; velocity.

6. What is meant by momentum? Upon what two things does the momentum of a body depend?

7. Prove by an example that the effect produced by a force is the same whether the body on which the force acts is at rest or in motion.

8. How can we determine the direction in which a body will move, when we know the direction of two different forces that are acting on the body at the same time?

9. Why should a body dropped in a rapidly moving car, strike the floor immediately below the point from which it fell?

10. Why should a large cannon-ball move more slowly than a small marble, when both are struck equally hard with a mallet?

Chapter VI.—The Mechanical Powers.

1. If no energy is gained by a machine, how is it that by means of a simple machine, like a lever, a weight of 200 pounds can be raised by a force of one pound?

2. Name the different mechanical powers. Of which two of these are all the others modifications?

3. Into what three classes may levers be divided? In which of

these is the velocity of the weight always greater than the velocity of the power?

4. Give two examples of each class of levers.

5. What relation must exist between the arms of a lever of the first class, in order that thirty pounds may raise 2240 pounds?

6. What must be the diameter of the axle of a wheel and axle, the diameter of the wheel being five feet, in order that a force of twenty pounds, applied at the handle, may raise 1000 pounds?

7. What two kinds of pulleys are there? In which is there a gain in the intensity of the power?

8. Why is a weight more easily raised through a given height by means of an inclined plane than it would be if raised directly through such height?

9. Name some of the uses of the wedge.

10. Why is it that so great a pressure can be exerted by means of a screw?

Chapter VII.—Gravitation.

1. Explain the cause of weight.

2. How many kilogrammes are there in one ton of 2000 pounds avoirdupois?

3. Prove by means of an experiment that the force of gravity acts vertically downwards towards the earth's centre.

4. Define centre of gravity. How may the centre of gravity of a rectangular plate of tin be found experimentally?

5. Why should a body supported at its centre of gravity be at rest or in equilibrium?

6. What three kinds of equilibrium may a body have when it is supported on an axis around which it can freely turn? What are the relative positions of the point of support and the centre of gravity in each of these kinds of equilibrium?

7. Upon what does the stability of equilibrium of a body resting on a horizontal surface depend?

8. Why does a person hold himself upright while carrying a load on his head?

9. Prove by means of an experiment that the velocity of fall of a body is independent of its weight.

10. Define pendulum. Which oscillates the more rapidly, a short pendulum or a long one?

Chapter VIII.—Some Properties Peculiar to Solids.

1. Name some of the properties peculiar to solids.

2. Define malleability. Give some example showing the great extent to which gold is malleable.

3. Describe an experiment by means of which fine wires or threads of glass may be obtained.

4. What properties possessed by steel render this substance so valuable for cutting tools?

5. Define tenacity. What is the cause of tenacity? Name some very tenacious substances.

6. Why are all structures limited in size?

7. In what different ways may the elasticity of solid substances be made manifest?

8. Is glass elastic? Describe any experiment proving the correctness of your answer.

9. Define crystalline form. Describe an experiment by means of which crystals of alum may be obtained.

10. Name some practical applications of elasticity.

Chapter IX.—Cohesion and Adhesion.

1. What name is given to the attraction that holds together molecules of the same kind of substance? What name is given to the attraction that holds together molecules of different kinds of substances?

2. Why will not broken glass or crockery cohere when the broken edges are pressed firmly together?

3. Describe an experiment showing the cohesion of two freshly-cut surfaces of lead.

4. Do liquids cohere? How can you prove this?

5. Give some instances of the adhesion between different solids. Between solids and liquids.

6. A capillary tube is plunged in a liquid which wets it; will the liquid in the tube be elevated or depressed? Why?

7. Give some examples of the phenomena of capillarity.

8. How may capillary tubes of glass be made?

9. Does adhesion ever occur between different liquids? Prove your answer by any example.

10. Why does the smell of tobacco smoke adhere to clothes?

Chapter X.—Liquids at Rest—Hydrostatics.

1. Why will not a jet of liquid thrown vertically upwards reach the level of the liquid in the vessel from which it is escaping?

2. Describe the artesian well. Illustrate by a drawing.

3. Why must any pressure exerted on a liquid mass be transmitted equally well in every direction?

4. Describe the hydrostatic press.

5. The areas of the large and small cylinders of a hydrostatic press are 10,000 and 1 square inches, respectively; what force on the small cylinder will be required to produce a pressure of 200,000 lbs.?

6. Prove experimentally that a body weighed in water loses as much weight as the weight of the water it displaces.

7. When will a body float in a liquid? When will a floating body be in equilibrium?

8. Define specific gravity. With what substance do we generally compare the specific gravity of solids and liquids?

9. The specific gravity of gold is 19.30; what is the weight of 218 cubic inches of gold?

10. How can the specific gravity of a liquid be determined by means of a hydrometer?

Chapter XI.—Liquids in Motion—Hydraulics.

1. What causes a liquid to run out of an opening in the side of a containing vessel?

2. Why should a greater amount of liquid escape from an opening near the bottom of a vessel than from an equally large opening near the top?

3. Define head. How much must the head be increased in order that the velocity of escape may be increased fourfold?

4. What causes the water to run out of the water-faucets in a house?

5. What causes the flow of water in a river? In what parts of a river is the velocity the greatest?

6. Describe the undershot water-wheel.
7. How are the buckets shaped in the overshot water-wheel?
8. How are the buckets in the breast-wheel enabled to retain the water to the lowest part of the wheel?
9. What is the cause of waves?
10. How can you prove that the water does not move forwards in waves?

Chapter XII.—Gases at Rest or in Motion—Pneumatics.

1. If the oxygen in the atmosphere is heavier than the nitrogen, why does it not settle in a layer near the surface of the earth?
2. What causes a balloon to rise through the air?
3. How did Torricelli discover the fact that the atmosphere exerts a pressure on all things on the earth's surface?
4. How do we know that the atmosphere, at the level of the sea, exerts a pressure of fifteen pounds on each square inch of surface?
5. Describe the barometer.
6. Name some of the uses of the barometer.
7. Describe any experiment illustrating the pressure of the atmosphere.
8. What effect has an increase of pressure on the density of a gas? What effect has it on the volume?
9. Describe the suction-pump for water.
10. Why cannot the suction-pump raise water higher than thirty-four feet from the level of the well to the body of the pump?

Chapter XIII.—Sound.

1. How is the sound of a bell carried from the bell to the ear of a listener?
2. Prove that sound-waves spread upwards, downwards, and in all directions.
3. Why cannot sound be carried across a vacuum?
4. Describe the string-telephone.
5. What is the velocity of sound in air at 32° F.?
6. Explain the cause of echoes.

7. What effect has the distance we are from a sounding body, on the loudness or intensity of its sound?

8. Describe the speaking-trumpet.

9. What is the cause of differences of pitch or tone?

10. What is meant by the quality of musical sounds?

Chapter XIV.—The Nature of Heat. Expansion.

1. What is the cause of heat? How does it differ from the cause of sound?

2. How do hot bodies give off their heat?

3. Is heat a form of energy or a kind of matter?

4. Describe the construction of a thermometer.

5. Give the rule for changing the degrees of temperature of the Fahrenheit scale into those of the Centigrade scale.

6. How do solids, liquids, and gases compare in the amount of their expansion when heated to equal degrees?

7. What is meant by the temperature of the maximum density of water?

8. What effect has the temperature of the maximum density on the freezing of large bodies of water?

9. How may the expansion of gases by heat be shown experimentally?

10. Describe the division of the thermometer scale into degrees.

Chapter XV.—The Communication of Heat. Surface Action.

1. By what means is heat communicated through solids? By what means is it communicated through liquids and gases?

2. Why are very porous materials such poor conductors of heat?

3. Explain the effect produced by conducting power on apparent temperature.

4. Describe the manner in which heat, applied to the lower parts of a liquid mass, is communicated to all parts of the liquid.

5. By what means do heated bodies radiate their heat?

6. What relation exists between the reflecting and radiating powers of bodies for heat?

7. What relation exists between the absorptive and emissive powers of bodies for heat?

8. In which will water heat the more rapidly, in a new, brightly polished tin vessel, or in one which is dull or covered with soot? Why?

9. Prove that heat is radiated equally well in all directions.

10. Why do blankets keep us warm?

Chapter XVI.—Change of State. Latent Heat. Steam.

1. What is the general effect produced on matter by heat?

2. Explain the nature of latent heat.

3. When does latent heat appear as sensible heat?

4. Why does a mixture of salt and ice, or salt and snow become so cold?

5. Explain the cause of the production of cold by evaporation.

6. Name the circumstances that increase the rapidity of evaporation.

7. When does the invisible moisture of the atmosphere become visible as fog, cloud, dew, rain, hail, or snow?

8. Describe the culinary paradox.

9. Describe the experiment of boiling water in a paper bag.

10. By what means can the temperature of water be raised above 212° F.?

Chapter XVII.—The Nature and Sources of Light. Action of Matter on Light.

1. What is the cause of light? Is it similar to the cause of heat?

2. Explain the cause of vision.

3. Define opacity; transparency, and translucency.

4. Prove that light moves in straight lines.

5. Explain the cause of shadows.

6. Distinguish between diffusion and reflection.

7. Describe any experiment illustrating the reflection of light.

8. What is meant by the refraction of light?

9. Why does a straight stick appear bent at the part which enters clear water obliquely?

10. What effect has the distance from a luminous body on the intensity of its light?

Chapter XVIII.—The Formation of Images. Color.

1. Explain the cause of the inversion of the images produced by small apertures.
2. In what direction will all visible objects appear?
3. Define visual angle. What effect has the visual angle on the apparent size of an image?
4. Explain the effect produced by the refraction of light on the apparent direction of a body.
5. What are lenses? Why do objects viewed through lenses appear differently than when viewed directly?
6. Describe the structure of the human eye.
7. Describe the construction of the camera-obscura.
8. What is meant by the dispersion of light?
9. What is the cause of color?
10. Will a red object appear red if illuminated by pure yellow light? Why?

Chapter XIX.
Electrical Charge, or Electricity of High Tension.

1. In what two ways may electrical energy be manifested?
2. Name some of the effects produced by electrifying a body.
3. State the laws for electrical attractions and repulsions.
4. How can the kind of electricity with which a body is charged be determined by the use of an electroscope?
5. Describe the electrophorus.
6. Describe the plate electrical machine.
7. What is the cause of lightning? What causes thunder?
8. Name some of the precautions that must be taken in the construction and erection of lightning-rods.
9. Name some of the effects produced by an electrical discharge.
10. How may electrical effects be obtained by means of a board, a sheet of paper, and a piece of India-rubber?

Chapter XX.—Effects Produced by an Electrical Current.

1. Describe the simple voltaic cell. Illustrate by a drawing.

2. What is meant by making or closing a voltaic circuit? What is meant by opening or breaking a voltaic circuit?

3. Enumerate the effects produced by the passage of an electrical current.

4. By what means may powerful electrical currents be caused to produce an intensely bright light?

5. What is the cause of the Aurora Borealis?

6. Describe the process of electro-metallurgy.

7. Distinguish between an electro-magnet and a permanent magnet.

8. Why does the magnetic needle point to the geographical north?

9. Describe the Morse system of electro-magnetic telegraphy.

10. What are magneto-electric currents? How are they produced?

THE  END.