ELEMENTARY MECHANICS

FIRST YEAR'S COURSE

BY

J. WILLIAMS

HEAD-MASTER OF SANFORD STREET BOARD SCHOOL, SWINDON

W. & R. CHAMBERS
LONDON AND EDINBURGH

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1883

REQUIREMENTS OF CODE, 1883.

SPECIFIC SUBJECT NO. 3 (A.), SCHEDULE IV.

MATTER IN ITS THREE STATES—SOLID, LIQUID, AND GASEOUS. THE MECHANICAL PROPERTIES PECULIAR TO EACH STATE.

MATTER IS POROUS, COMPRESSIBLE, ELASTIC.

MEASUREMENT AS PRACTISED BY THE MECHANIC—MEASURES OF LENGTH, TIME, VELOCITY, AND SPACE.

PREFACE.

Of all the 'Specific Subjects' now being taught in our Elementary Schools, perhaps none is more important than 'Mechanics.' The lessons given in this little book cover the first year's course of the subject as set forth in Schedule IV., Scheme A., of the Code for 1883.

The great object has been to place before the children a small but definite amount of knowledge, and to teach them how to apply that knowledge in their everyday life.

It should be clearly understood that this book is only intended to *supplement* the lessons given by the teacher. In all cases, practical experiments should be performed, and the children encouraged to make experiments for themselves.

The last chapter has been added in order to awaken an interest in our common industries, and also to encourage the children to notice the application of the properties of matter, of which they have learned something in this course.

The recapitulatory chapters will be found useful, it is hoped, in gathering together the main points in the preceding lessons.

At the end of the book will be found Examination Questions, which can be multiplied at will by the teacher. A list of the principal terms used, with their derivations, has also been added.

J. W.

Swindon, *August* 1883.

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ELEMENTARY MECHANICS.

CHAPTER I.

MATTER IN ITS THREE STATES.

Mechanics is the science which teaches us the properties and motions of matter.

By **matter** we mean anything which we can perceive to exist by any of our senses. We have five senses, namely, seeing, hearing, tasting, touching, and smelling. Everything around us, the school, fields, desk, streets, &c., is matter. Now each kind of matter possesses some peculiarity which belongs to itself. For instance, sugar is sweet ; iron is hard ; clay is soft ; apples may be sweet or sour. These attributes we call **properties.**

A portion of matter whose size is limited is called a **body.** Every body is made up of minute particles called **atoms. These atoms** adhere to each other, and **are the smallest divisions of matter** we can conceive.

A body may be either **simple** or **compound.** All atoms of simple or elementary bodies are of the same kind of matter; but the smallest portion of a compound body contains several atoms of different kinds of matter. The smallest bunch or cluster of atoms which can exist by itself is called a **molecule.** For instance, if we break a piece of chalk into the smallest pieces possible, each of these tiny pieces is a molecule ; but every one of these molecules contains five atoms, namely, one of lime, one of carbon, and three of oxygen. So you see that chalk is a compound body. In fact, almost everything that we see around us is a compound.

Now it will readily occur to you that matter may be found in different states, namely, as **solids, liquids,** or **gases.**

Solids.—In all solids the molecules are united very closely together, and cannot easily be separated. Take, for instance, a piece of wood or iron. No matter how you place it, the size and shape will be the same. Now try to press it out of shape. It is firm, and will not easily give way. Of course, we could alter the size and shape, but to do so we should have to use much force. We may therefore say **of a solid** that **the particles are united very closely together**, and that **it resists any attempt to alter its shape or its size.** The attraction of its particles for each other is very strong, and great force is necessary to separate them.

Liquids.—Now let us examine another kind of matter. Water is perhaps the best example. We cannot handle a quantity of water as we can a piece of wood or iron. If we pour it on the desk, it will run off on to the floor. We can, however, pour it into a vessel, like a glass, a bottle, or an ink-stand; and it will readily accommodate itself to the shape of the vessel. The attraction of the particles in a liquid is not so strong as in a solid. **Liquids**, however, **retain their size, although they easily change their shape.** You cannot, under any circumstance, press a pint of water into a half-pint glass. The shape is of no importance, but enough room must always be allowed a liquid. If not supported at the sides, liquids have a tendency to spread out. Another thing which you will notice about liquids is, that they always try to find their own level. Water will move about in a vessel until it makes its surface level, and then it becomes quite still. **A liquid** may, then, be defined as **matter whose particles have but little cohesion**, and **which will easily change its shape** according to the vessel which contains it, **but always retain its proper size** under ordinary circumstances.

Gases.—**Gases, like liquids, have no shape of their own.** Their **molecules have no attraction for each other**; in fact, they repel one another, and endeavour to expand. In this way, a small quantity of gas will spread itself out so as to fill a large vessel. **A gas**, unlike a liquid, **can be easily compressed**, that is, be made to occupy a smaller space. By this means a large quantity of gas can be forced into a small vessel; but as soon as the pressure is removed, it will spread out in all directions and regain its former dimensions. To define **a gas**, we may say that it **is**

matter having no size or shape of its own, and whose particles have no cohesion.

Liquids and gases have many properties in common, and so we sometimes use the term **fluid** to denote either the one or the other. We will now consider certain properties which are common to all kinds of matter, whether solid, liquid, or gaseous.

(1) **All matter must occupy a certain amount of space. This property we call extension.** No two things can occupy the same space at the same time. We may speak of the extension of a body, either in respect to its length, its surface, or its bulk or volume. We shall by-and-by consider these measurements more fully. Sometimes we call this property **impenetrability**, because it is impossible for one portion of matter to enter a place which is filled by another portion. When water is poured upon a heap of sand, it at once disappears. It does not, however, penetrate the molecules of sand, but simply fills up the small spaces between them.

(2) **Divisibility.**—This **is the property which all bodies possess of being capable of division into small but distinct parts.** Many instances can be given to show the extreme divisibility of matter. By using the microscope, we see that a drop of water contains innumerable small animals called animalcula. A very small piece of the skin which covers our hand is seen to contain many little horny scales which might readily be separated. In fact, it has become a question as to whether there is a limit to the divisibility of matter. It is because we think there must be a limit that we say, **all bodies consist of very minute invisible parts called atoms.**

(3) **Weight.**—The earth draws everything towards it, owing to the force of **gravitation.** Thus, if a ball is thrown into the air it will fall to the ground. Some substances fall with more force than others. For example, a stone will descend more rapidly and with more force than a feather. This force with which a body is attracted towards the earth is called its weight. Comparing the stone with the feather, we should say that the former was heavier than the latter. All matter possesses the property of weight. Even common air, which, although we cannot see it, fills all vessels, has been weighed. Bear in mind, then, that the earth attracts everything towards it, and that **the exact amount of**

support necessary to stop any form of matter from going towards the earth is equal to its weight.

Indestructibility of Matter.—It is very important for us to know that **we cannot destroy matter, try how we may.** We may change the state of matter, but we cannot destroy it. Put a handful of salt into a bucket of water; the salt at once disappears, but is not destroyed, for we can detect it by tasting the water. If we evaporate the water in the bucket, we shall find the salt left behind undiminished in amount. Take as another instance our common coal. By burning it we change its state. The gases given off mix with the oxygen in the air, forming carbonic acid gas, &c., and are conveyed away by means of the chimney. The ashes remain. The carbon, which really makes the difference between the ashes and the coal, is not destroyed; it has only taken some other form and position in the universe. And so with all matter. We can change it by burning, &c., but in no case can we destroy it.

CHAPTER II.

PROPERTIES OF SOLIDS.

Extension.—We have already learned that all matter must occupy some space, or in other words, must possess the property of extension. We shall now consider the force of cohesion.

Cohesion is that force which binds together the particles of a body. The force of cohesion is not equally strong in all solids. For example, the particles of iron are very closely held together, or in other words, the force of cohesion is very strong in iron. The particles in a piece of chalk are not so closely united, for the force of cohesion is not quite so strong in chalk as in iron. Cohesion varies very much according to the arrangement of the molecules, even in the same bodies. For instance, the cohesion in a piece of wood is stronger in one direction than in another. We all know that it is easier to separate the particles 'with the grain,' as we call it, than against it. It is the change in the arrangement of the molecules which makes the difference between untempered and tempered steel. The force of cohesion is much stronger in tempered steel than it is in untempered steel. Closely allied to this property is that of **adhesion**, which may be defined as **that property by which the surfaces of bodies will become united when brought into contact.** You all know how cement will stick to a rough brick or stone wall. If two pieces of plate-glass, equal in size, be pressed firmly together, they will adhere, and cannot be separated without being broken. A common example of this power of adhesion may be seen every day in school. When your teacher writes on the blackboard, it is the power of adhesion which unites the chalk to the surface of the board. The power of adhesion is very weak in some bodies. To unite their surfaces, we use plaster, glue, gum, solder, or some other substance which will assist them to adhere. When a mixture of tin and quicksilver is spread upon a sheet of glass, the mixture adheres to the glass, and a mirror or looking-glass is made. **When the force of cohesion** between the various particles of a solid **is destroyed, it is difficult to restore it.** We cannot make the pieces of a broken slate unite, because we cannot arrange all the particles so as to restore cohesion. Glass can be restored after breakage by fusing the pieces into which it is broken, and thus uniting them. It has now become common to mend broken glass-ware by the use of adhesive cement.

Cohesion may be defined as **the force which the particles of matter exert to keep themselves together.** When cohesion is destroyed, it is difficult to re-unite these particles. **Cohesion in solids is usually very strong.**

Expansion.—Bodies may be expanded by applying heat, which lessens the force of cohesion, and allows the particles to increase in size. Suppose we have a glass tube, and a brass ball which under ordinary circumstances will just pass through it. If we heat the ball, it will be too large to go through. Before regaining its normal size, it must be cooled. Thus you will see that **heat expands solids, and cold contracts them.** We shall notice several instances of this later on. Take, however, the common one of bursting a glass by filling it with hot water. Why does the glass crack? The hot water expands the inside of the glass more quickly than the outside, and in consequence the two parts must separate. Thus the glass is broken. Then, again, how often you must have noticed that in making a wheel, as soon as the frame is complete, the iron band or tire is made red hot; then it is fitted tightly on the ring of felloes, and afterwards is thrown into cold water. Now let us consider why this is done. The tire is made red hot in order to expand it. In this state it is made to fit tightly round the wheel; but when thrown into water and cooled, the iron contracts or gets smaller, so that when cold, it fits more tightly still, and it is then almost impossible for the tire to slip off the rim of the wheel. When railway metals are laid, a space is always left between the ends of the rails, to allow of expansion in hot weather.

When very great heat is applied, most solids are converted into liquids.

Compressibility.—This **is the property by which bodies may be made to occupy less space without losing weight.** A body which can be compressed must be more or less porous, for it is by pressing its particles more closely together and stopping up the minute spaces which are between these particles, that we can force a body into smaller space. Some solids, such as sponge, cork, clay, &c. can be compressed very easily, even by the hands. **Every solid is to some extent capable of compression.** This is well shown in making our common coins. The die is impressed on the metal by forcing the molecules more closely together. Solids can only be compressed to a certain extent. If too much pressure be used, they will be broken or crushed into a powder.

Ductility.—This property **enables a solid to be drawn out into a wire.** The metals are very ductile, iron and gold being particularly so. Certain bodies, such as clay, putty, &c. are ductile at ordinary temperatures, and can be drawn out and modelled with the fingers. Other bodies, such as glass, must first be heated. In a heated state, glass can be drawn out into very fine threads resembling floss silk. The machines used for the production of gold, silver, or copper wire are the rolling-mill and the draw-plate.

Malleability.—The property by which bodies can be rolled or hammered out into thin sheets without breaking, is called malleability. The degree of malleability varies very much in different bodies. Gold is the most malleable of all metals. So malleable is this metal that it can be hammered into sheets, called gold-leaf, so thin that it would take 300,000 of them piled one on the other to become an inch in thickness. Other metals, such as silver, copper, Dutch-metal, &c. are very malleable. Lead is also very malleable, and is used in thin sheets for lining tanks, covering roofs, &c. Iron, when heated, can be rolled out into sheets and plates.

Tenacity.—We can break some solids much more readily than others. For example, wood is more easily broken than iron. We express this by saying that iron is more tenacious than wood. **Tenacity**, then, **is the resistance which bodies offer to being broken, when subjected to stretching or traction.** We can measure the tenacity of a solid by seeing how heavy a weight a piece of a given length and thickness will support without breaking. A wire is used to measure the tenacity of a metal. Steel is the most tenacious of our common metals; hence it is used where we want great strength. Our newest ships of war have steel armour-plates. Tenacity not only varies in different bodies, but also in the same body. The amount of resistance offered depends upon the closeness of the particles to each other. Wood is more tenacious when the weight is applied with the grain than it is when applied in the opposite direction. Tenacity differs, too, with the form of bodies. A hollow cylinder offers greater resistance than a solid one of equal mass and weight. This knowledge is applied in the construction of arches to support heavy buildings, &c. Solids which have great tenacity and can be bent without breaking are said to be **tough.** Gutta-percha, leather, and cane are examples of tough bodies. Bodies which, when bent, readily break are said to be **brittle.** Examples of such are glass, slate, &c.

Hardness is that property by which solids resist being scratched or worn by others. The diamond is the hardest substance known. It will scratch other substances, but cannot be scratched by them. Stone is harder than clay, but softer than steel. We often find it necessary to harden metals, so that they may be much more commonly used. Two soft metals will often, when combined, form a hard compound. The gold and silver used for coinage are hardened by mixing them with copper. Bronze is a mixture of copper and tin. When metals are thus mixed, we term them **alloys** (Fr. *à loi*, according to the law). Iron mixed with a very small quantity of gold is said to be superior to steel for cutting-instruments. Steel is, however, most commonly employed for tools which require great hardness.

Elasticity.—Some bodies, when altered in shape and size by pressing, stretching, twisting or bending, have the power to regain their former size and shape. For instance, if we stretch an elastic band or squeeze a hollow india-rubber ball, we alter their sizes and shapes ; but as soon as we cease to stretch or squeeze, these articles return to their original forms and sizes. The power which these bodies must possess in order to do this is called elasticity, and all bodies having this power are said to be elastic. Some bodies are more elastic than others. Those like india-rubber, steel, ivory, &c., which, after alteration, return exactly to their former size, are said to be **perfectly elastic**; whilst those like cork, wood, copper, &c., which only partly return, are said to be **imperfectly elastic.** If we roll up a piece of dough or putty into a ball and drop it to the ground, we find that after striking the floor the ball is flattened on one side. We see, then, that putty and dough are **inelastic bodies**, that is, they have no elasticity. If we drop an india-rubber ball, a marble, or an ivory ball, we find that after striking the floor it is just the same shape as before. Now, although we may not have noticed it, the ball or marble was flattened, like the putty and dough, by striking the floor, but, unlike them, it has regained its former shape. This can be proved by covering the ball or marble with oil or wet paint before letting it fall. We can then see by the mark left on the ground that the ball was flattened when it fell. We might also notice that the elastic bodies rebounded, whilst the inelastic did not. This rebound is caused by the ball becoming round again after being flattened. We may therefore say that **elasticity is the force which a body exercises to counteract any change in its size or shape.**

Divisibility.—Every substance is composed of a number of small pieces called particles, bound together by cohesion. When this cohesion is destroyed, these particles are separated. No one, however, has yet been able to divide a substance so small that it is impossible for the little particles to be further divided. For example, if we take a piece of chalk and crush it to powder, we may, with a very strong microscope, discern in each grain a large number of tiny shells. A single drop of water, as we have said, contains myriads of animalcula. If we crush a piece of sandstone and examine the sand with a microscope, each grain will appear capable of further division. Thus we see that the limit of divisibility is unknown. All that we know on this subject is, that the smallest portions which we can conceive to exist are called **molecules,** and that **each molecule contains several atoms.**

Gravity.—All bodies, however large or small they may be, **attract each other to some extent. This attraction varies according to the size of the bodies, and the distance at which they are apart.** A large body has greater power of attraction than a small one at the same distance. Let us suppose that we have three bodies floating about in space, each two miles apart. Let the third be four times and the second twice as large as the first. Then the third will have just twice as much attractive power as the second, because it is just twice as large. Now, let us suppose that the third is moved two miles further away, so that it is now four miles from the first, whilst the second is still only two miles away. Although the third is twice as large as the second, and has twice its attractive power at the same distance, the power of the second will now be just equal to that of the third. From this we see that the greater the distance the less the power of attraction will be.

When a stone is thrown up into the air it returns to the earth, because the earth, being much larger than the stone, has most attractive power, and consequently draws the stone towards it. We say the stone falls, but we now see that it is drawn to the ground by this power called **gravity.** Take another example. Whilst at tea, you may have noticed a small tea-stalk which rises to the surface of the tea in your cup. It moves about for a little time, as if uncertain what to do; then all at once it darts towards the side of the cup, and stops there. In this case, the cup has the greater amount of attractive power, and so the tea-stalk is drawn towards it. Whatever shape a body may be, and whatever its position, its attractive power always acts through a certain point. This point is called the **centre of gravity.** To balance a stick on end on the tip of our finger, we must keep the stick in a vertical straight line above the point where it touches the finger. The centre of gravity is said to be in this line. If the stick leans, its centre of gravity is no longer in the vertical line from the finger-tip, and the stick will fall.

Weight.—We have already explained weight as **the force with which any body is drawn towards the earth,** and that this is owing to the force of gravity of which we have just spoken.

Porosity.—We have also seen that by the application of heat we can expand solids, and that we can compress them, that is, make them occupy a smaller space, by using pressure upon them. Unless there were spaces between the particles of which these solids are composed, we could not do so. These spaces are very minute, and are called **pores.** All bodies are more or less porous, although in many cases we cannot see the pores. In some solids, as sponge, bread, pumice-stone, the pores can be clearly discerned. Porous substances are extensively used. For instance, the porous substance charcoal is used in most filters to purify the water. The pores are so small that only the pure water can pass through them, the impurities being kept behind. Common blotting-paper is very porous, and at once absorbs the ink which is not dry on your writing-books. **We may, then, define porosity as that property or state which bodies possess of having small spaces or pores between their molecules.** It is this property which gives rise to **absorption,** which **is the power to suck in the particles of another body.**

Structure of Solids.—In a former lesson we learned that the smallest portion of a body which can exist is called a molecule, and that every molecule contains a number of atoms. In some bodies these small portions of matter are arranged in a regular order, and are very close together, whilst in others, no definite form or order can be discerned. The molecules of some bodies are fibres or threads. These bodies are called **fibrous.** The best example of this kind of body is wood, which is easily divided into thread-like splinters by splitting. The molecules of fibrous bodies have far greater cohesion in one direction than in the other. A cane will split much more readily than it will break into two short pieces. We turn this knowledge to account in splitting wood, by cutting in the same direction as the grain runs. Bodies which consist of very small grains are called **granular** bodies. Sandstone and granite are bodies of this kind.

Those bodies which show no definite form or structure, and are as easily divided in one direction as in another, are called **amorphous,** or **shapeless** bodies. Clay, chalk, dough, &c. afford good illustrations of this class. Other bodies are, however, a collection of smaller bodies, each having a definite form and arranged in definite positions. **Crystals** are bodies of this class. The most beautiful of all crystalline bodies is the diamond. Sugar, soda, and alum are common forms of crystals. Snow also is composed of very beautiful and minute crystals. The formation of a crystal prevents any dirt or impurity from being between the minute crystals which combine to make the larger one. **Crystals are therefore necessarily pure,** and are generally very brilliant. This knowledge has led chemists to crystallise their goods in order to purify them.

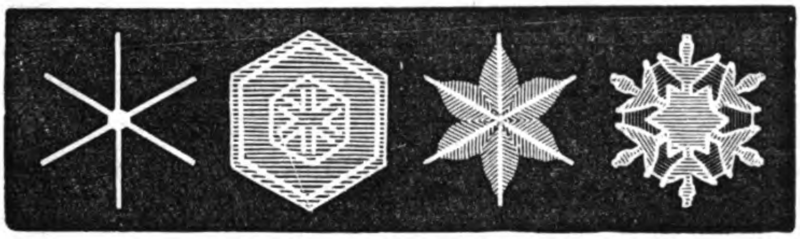


Fig. 1.—Snow-crystals.

The forms of the crystals in different bodies vary very much; but in all crystalline bodies of the same kind, the crystals are of the same form. Thus, in alum all the crystals have four points; but all snow-crystals have six points.

Bodies, then, which are made up of minute but regularly formed crystals are called **crystalline** bodies.

In some bodies the particles are very closely welded together, and offer resistance to any force acting upon the body, no matter in what direction this force may be applied. These bodies will not easily change their shape, even when subjected to great pressure or twisting. We term these bodies **rigid.** Steel and iron goods give us a good example of rigidity.

CHAPTER III.

PROPERTIES OF LIQUIDS.

Liquids have but little Cohesion.—Whereas the particles in a solid are bound firmly together, those of a liquid are free to move and take up fresh positions. Whilst we always expect a solid to have a size and shape of its own, we do not expect so much of a liquid, for as its particles are free to take up any position, the shape of a liquid will altogether depend on the form of the vessel which contains it. **Liquids**, then, **have but little cohesion.**

They retain their Size.—Liquids admit of but very little compression. You cannot force a gallon of milk into a half-gallon milk-can. To prove this, let us suppose that we had a sheet of iron which would just fit into the milk-can, so as to be what is called water-tight, that is; so closely fitted that no water can escape at its edges. If we put half a gallon of milk in the can, it will be quite full. Now, let us place on the top our sheet of iron, and then press heavily on the top of that with a weight. We shall find that the milk in the can does not decrease very much in bulk, however much weight we use. If we use very great pressure, the milk will burst the sides of the can. From this we see that **liquids admit of but little compression.**

Transmission of Pressure.—If, instead of milk, our can had contained a solid, we might have compressed its contents to a considerable extent. In all probability, however, we should, ere this occurred, have forced out the bottom of the can. We should not, however, have burst the sides. Let us see what we can learn from this. When we press on the surface of a solid, each molecule in that surface is pressed against the molecule underneath. This pressure is continued from the top to the bottom, but not in any other direction. We then see that **solids transmit pressure only in one direction,** namely, towards the surface opposite to the one on which pressure is applied; but with a liquid, the pressure is transmitted in every direction. To burst out the sides of the can, it is plain that the pressure exerted on the top must not only be transmitted towards the bottom, but also from one particle of the milk to another in a side direction. That there would be an **upward pressure** is very evident, for we should feel the resistance to the force which we use. Here is another instance. Suppose that in a vessel we have holes in the bottom and sides, which we can close at will. Close all the holes, and fill the vessel with water. Then open the hole at the bottom. The water will run out owing to the **downward pressure**. Close this hole, refill the vessel, and then open all the holes at the sides. The vessel will soon be emptied by these openings, owing to the **lateral** (side) **pressure** of the water. **Liquids, then, transmit pressure in every direction.** The pressure increases with the depth of the liquid. Suppose that in the vessel above mentioned (fig. 2) all the holes are of equal size, but those in the sides are at various heights. If we measure, we shall find that the greatest quantity comes from the hole in the bottom, and that of all the others, the one nearest to the bottom emits a greater quantity than any hole above it. The quantity which escapes by each hole gets less as we approach the top. We shall further notice, that from the holes in the side the jet of water from the lowest, D, spurts out to the greatest distance; the lowest but one, C, being next greatest, and so on until we come to that from the highest, A, which rushes out but a very little way. Hence, the greater the depth the greater is the force by which the water is driven out. Let us try and make this a little plainer. Think of a volume of water as consisting of a number of thin layers. Then it is plain that the second layer supports a pressure equal

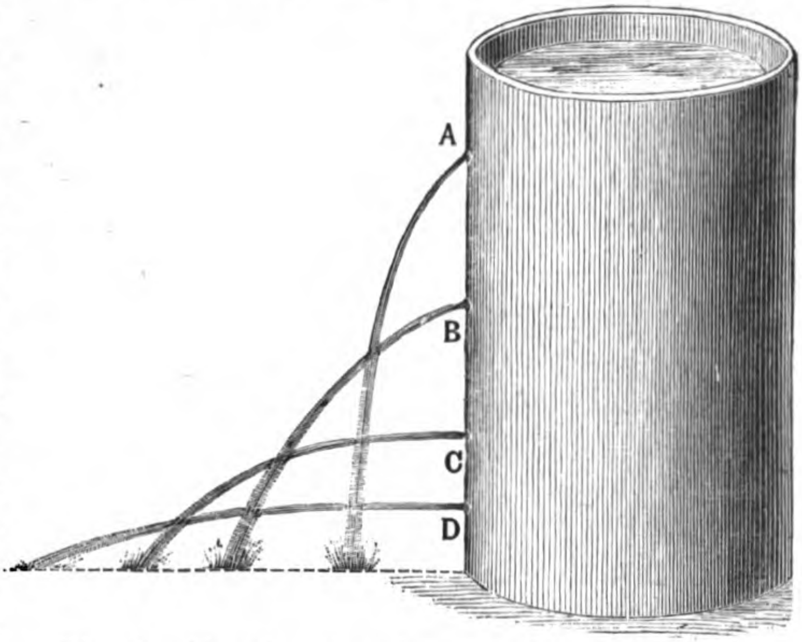


Fig. 2.—Showing that downward Pressure varies with the depth of a Liquid.

in weight to the top layer. The third supports a weight equal to that of the first and second, and so on to the bottom, so that the pressure of the bottom layer is powerful in proportion to the weight of all the layers above it. In other words, **the pressure of liquids is proportionate to their depths.** From this you will see how important it is that the sides of tanks, and the banks of reservoirs and docks, should be made very strong, so as to prevent the water from bursting them. We shall consider the importance of this principle more fully further on.

Water always finds its Level.—The molecules of a liquid always arrange themselves so that the surface is perfectly level. If you pour water quickly into a basin, it will splash and move about for a short time, and then become quite still. The surface then is level. Even if we have vessels of different shapes (as in fig. 3) joined together by a long tube, water poured into the tube will rise to the same height in each of the vessels. This principle is a very important one, and has given rise to several inventions. Have you ever thought how **fountains** are constructed? You will find that first of all a tank of water is placed at a great height; then a pipe connects the tank with the fountain. The water is turned on from the tank, and after running down the pipe, tries to rise to its own level, and therefore rushes forth from the fountain to a great height (fig. 4). We shall speak of this again in another chapter; but it will be well for you to notice a very common appliance used by mechanics when they want to produce a perfectly level surface. In order to see that their work is perfectly straight, they use a little instrument called a **spirit-level.** Its construction is very

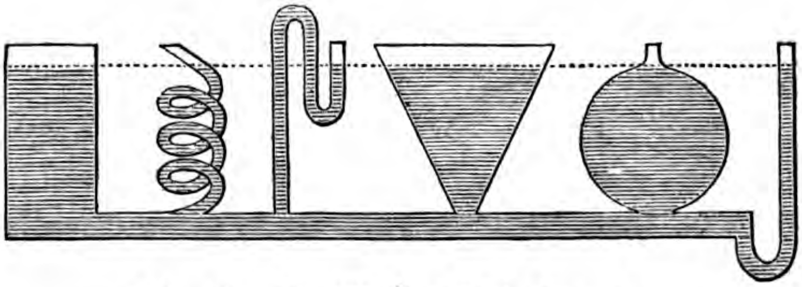


Fig. 3.—Liquids find their Levels.

simple. It consists of a slightly curved glass tube which

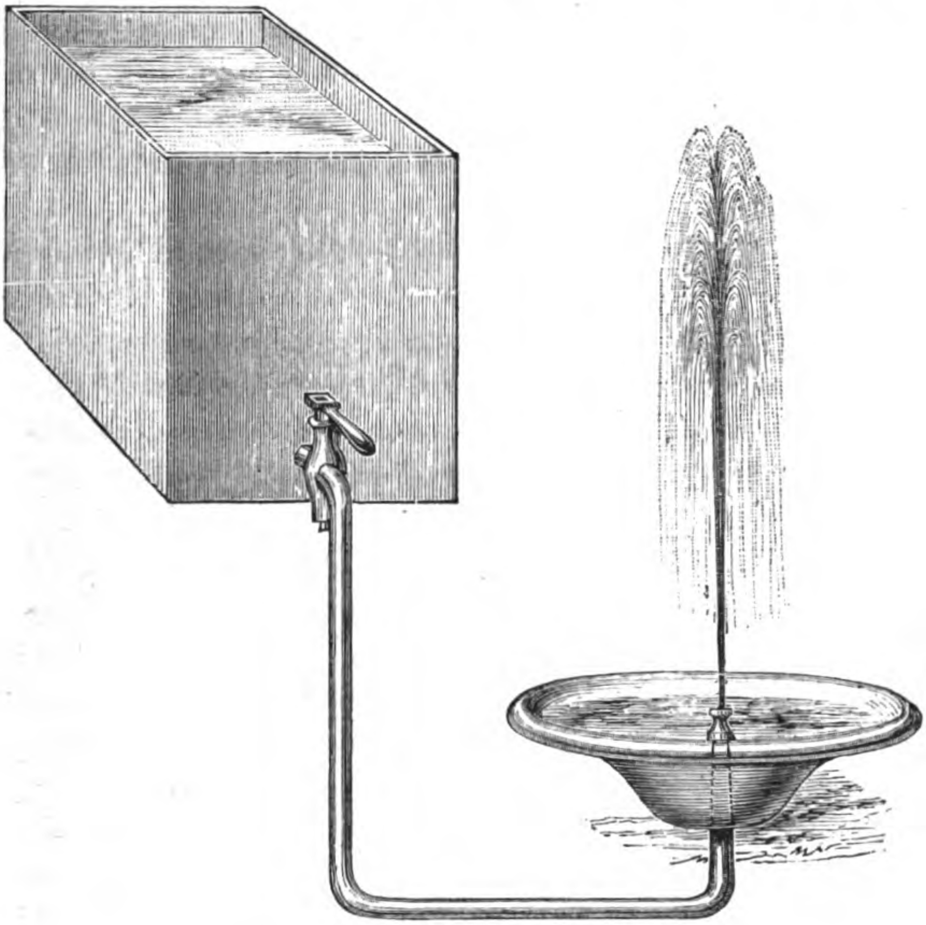
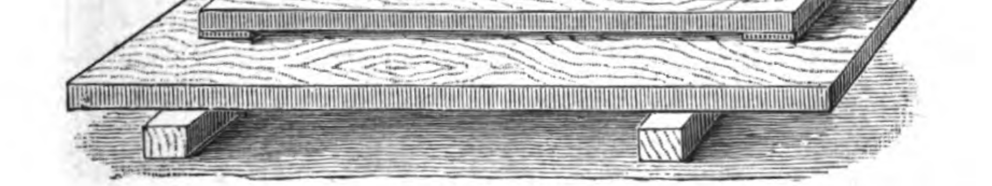


Fig. 4.—Fountain.

contains spirits of wine and a bubble of air (fig. 5). The



On a Level Surface. On an Inclined Surface.

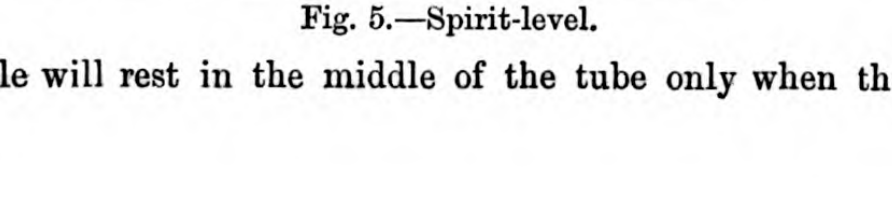


Fig. 5.—Spirit-level.

bubble will rest in the middle of the tube only when the two ends of the tube rest on a perfectly level surface. Should one end be higher than the other, the bubble will rush to that end. In order to protect the tube and make it easier to carry, it is generally fitted on a wooden case, the bottom of which is perfectly level.

Let us remember, then, that **one important property of liquids is that of finding their own level.**

Buoyancy.—We will now consider the upward pressure of liquids, or in other words, the buoyancy of liquids. **By buoyancy we mean the power a liquid has to bear up a body placed in it.** We know that if a cork be thrown into water it will not sink, but will float on the surface. This could not happen if the water had no buoyancy, for the weight of the cork would carry it to the bottom. Perhaps you will ask how it is that a stone equal in size to the cork does not float. If the stone, besides being of equal size, was also of equal weight, there is no doubt but that it would float; but since it is much heavier, its weight is more than the upward pressure of the water can support, hence the stone sinks. We know that a piece of pumice-stone would float, for pumice-stone has very little weight. To prove that extra weight will cause a floating body to sink, let us push, one after another, a few very small nails into the cork, and take notice of what happens after each nail is driven in. If we are careful, we can make the cork just heavy enough to sink a little way below the surface of the water. We shall, however, notice that it is floating about at a lower level. To enable the cork to do this, the water at this level must have greater buoyancy than that at the surface. By the addition of another nail, the cork is carried towards the bottom, but floats at a still lower level. Its weight is now too great to permit it to float at a higher level. We now see that the **buoyancy increases with the depth of the liquid.** By adding extra weight in the form of more nails, the cork can be made so heavy that it will not float at all, but, like the stone, it will sink to the bottom.

The amount of buoyancy varies with different liquids. Alcohol, which is a very light liquid, has but little buoyancy. Less weight would be required to sink the cork in alcohol than in water. Salt water has more buoyancy than fresh water; hence, it is easier to float or swim in salt water than in fresh.

Mercury has great buoyancy; even a piece of iron will float in mercury. Let us now notice another curious fact. We know that an iron ship will float; but if the iron were in a lump, instead of being shaped to form the vessel, it would quickly sink to the bottom of the sea. This is because the iron, when shaped to form the vessel, has a greater surface for the upward pressure of the water to act upon than the lump of iron has, so that the same weight being spread over a larger area has more buoyancy to support it. When a vessel is launched, that is, placed in the water, some of the water is displaced by the bottom of the vessel. If the vessel could be weighed whilst in the water, it would seem, although we know that it really is not, very much lighter than before it was put in. This is because the buoyancy of the water supports part of the weight. By experiment we may prove that this weight which a body seems to lose when placed in a liquid, is exactly equal in amount to the weight of the water which is displaced.

Specific Gravity.—When we wish to compare the weights of any bodies, whether solid, liquid, or gaseous, we must take an equal volume of each. Thus, if we are comparing the weights of olive oil and water, we weigh half a pint, a pint, or a quart of each, not half a pint of one and a pint of the other. It is, however, most convenient to take a certain quantity of some well-known substance, and compare the weights of all others with the weight of this substance. The substance selected for that purpose is called the **standard.** The weight of water is the standard used for comparing the weights of both solids and liquids. For gases, the standard we usually employ is air. **The weight of any substance, as compared with that of an equal volume of the standard, is called its specific gravity.**

To find the specific gravity of a liquid we require a pair of accurately adjusted scales and some weights. A bottle to contain the liquid is also necessary. First we find the exact weight of the empty bottle. Then fill the bottle with water, which is the standard, and weigh again. From the weight now obtained, deduct the weight of the bottle, and we have that of the water alone. If we empty the bottle and fill with each of the liquids we wish to compare, we can obtain the weight of each very accurately. Suppose we have been comparing the weights of water, olive oil, mercury, and ether, and that our bottle held just 10 lb. of water. Then we should find that it would hold 135 lb. of mercury, 9 lb. of olive oil, and 7 lb. of ether. If 1 lb. of water filled the bottle, then 13½ or 13·5 lb. of mercury, $\frac{9}{10}$ or ·9 lb. of olive oil, or $\frac{7}{10}$ or ·7 lb. of ether would also do so. The specific gravities of these liquids, then, are: water, 1; olive oil, ·9; ether, ·7; and mercury, 13·5. It will be found that **the greater the specific gravity, the more buoyant will be the liquid.**

We have said that to find the specific gravity of a solid, we use water as the standard. Let us now see how to find the specific gravity of a solid, as, for instance, a nugget of gold. First weigh the gold on the scales. Let us suppose it weighs 19 oz. Now fill a glass bowl just full of water. Then gently lower the nugget into the bowl. Of course, the bowl is made overfull, and water of exactly the same bulk as the gold is consequently pushed out. Weigh the water which overflows, and it will be exactly 1 oz. Gold, then, is 19 times heavier than water; and as the specific gravity of that fluid is 1, that of gold will be 19. The specific gravity of iron is 8, whilst that of lead is 11.

To find the specific gravity of a gas, a quantity of air and an equal volume of the gas must each be weighed at equal temperatures and pressures, and their weights compared.

Capillarity.—There are a few cases in which liquids do not follow the law of finding their own level; they sometimes rise above their level. For instance, in a paraffin lamp the light is kept burning by the oil passing from its level in the bowl to the flame above. Immersed in the oil, we have one end of a piece of porous substance called wick. The oil rises through the pores until the whole wick is saturated, and thus a steady light is maintained. You often see another common instance of this property. Hold a piece of loaf-sugar so that it just touches the tea in your cup; some of the liquid at once rushes up the pores in the sugar, and in a very short time saturates the whole lump. **This force by which a liquid will rise through the small pores between the particles of solids is called capillary force, or capillary attraction.** It is owing to this capillary force that blotting-paper absorbs ink.

Expansion of Liquids.—By applying heat to liquids, we get the same result as in solids. The force of cohesion is lessened, and the particles expand. If much heat be applied to a liquid, its particles will take a new form, as **vapour.** When we place a saucepan of water on the fire, as the water becomes heated it expands, until the vessel at length is unable to hold it, and part overflows. The remainder, if heated still further, is converted into steam, which forces its way out between the side and the lid of the saucepan. The value of this knowledge is best seen by the result of its application to the steam-engine, the invention of which has created a revolution in the manufactures of the present day.

Liquids can, on the other hand, be converted into solids, either by great pressure or by the action of cold. A familiar instance of the latter is the formation of ice from water.

CHAPTER IV.

PROPERTIES OF GASES.

A Gas has no Size or Shape of its own.—The particles of gases mingle with each other very freely. The force of cohesion is altogether wanting. The particles seem to repel each other, and endeavour to fill as much space as possible. The chief difference between a gas and a liquid is, that the former possesses the property of elasticity to a very great extent, whilst the latter does not.

Different kinds of Gases.—Some gases are easily convertible into liquids, or even into solids, by pressure or change of temperature. For instance, steam, which is a gas of this kind, can be turned into water by lowering the temperature. Further, by still lowering the temperature we can convert the water into ice. Gases of this kind are called **vapours.** On the other hand, some gases require great pressure and the application of extreme cold to thus convert them. Hydrogen and carbonic acid are examples of this kind of gas. We have still another kind of gas. All attempts to liquefy or solidify these gases have proved futile. Air is perhaps the best example of this kind of gas.

Such gases, owing to their being always the same, are called **permanent gases.** Let us remember that there are two ways of reducing a gas to a liquid: firstly, by subjecting it to a great pressure, and secondly, by cooling it. In most cases both these methods must be used.

Elasticity of Gases.—All gases are perfectly elastic. The smallest possible quantity of a gas introduced into a vessel at once (if there is a vacuum) spreads out and fills it. It has been proved that the elasticity of gases increases as their volume decreases, that is, the smaller the quantity of gas the greater is its elasticity. The air-gun is a good example of the application of this principle.

Gases transmit Pressure equally in all Directions.—We have said that liquids transmit pressure in all directions, and although this is strictly correct, we shall notice that the transmission is usually downwards, and from side to side. We may here point out the fact, that whilst a vessel which is to contain a liquid must have a bottom and sides, that which is to hold a gas must have a top also, for gases have much more upward pressure than liquids, and if not inclosed on the top they will escape. When a balloon is filled with gas, we see that the material of which the balloon is made is pressed outwards equally in every direction, at the top, bottom, and sides alike. If, when our balloon is filled, we press any part inwards, say at the top, we find that the inclosed gas resists the pressure on that part, and at the same time endeavours to press out the material in every other part to a greater extent. A hole made in any part of the balloon will allow the gas to escape. If we make a long glass tube air-tight by tying parchment over each end, and then press gently on one end, the parchment at the opposite end is forced outwards, the pressure being transmitted through the inclosed air. An apparatus such as we have just spoken of is called a **pneumatic tube.** Tubes constructed on this principle have been employed for the purpose of ringing bells, transmitting messages, &c.

Pressure of the Atmosphere.—Atmosphere is the name given to the air which envelops the earth on every side. It is composed of oxygen, nitrogen, and a very minute quantity of carbonic acid gas. The general composition of the air is the same at all times and in all places, although the production of carbonic acid gas increases year by year, owing to the quantity of coal used. The reason for this is, that trees and plants are continually decomposing the carbonic acid, using the carbon for their own nourishment, and restoring the oxygen to the air. The atmosphere, like all gases, possesses weight. This may be easily proved in the following way: Place a vessel, having a long neck fitted with a tap, upon an air-pump, and exhaust the air from within it. When this has been done, let the weight be ascertained by means of a very delicate balance. Then turn on the tap and let in the air. By weighing it again, it will be seen that the vessel is heavier than before. The difference between the weights will be the weight of the air which the vessel holds. Now, having proved that the air has weight, you will easily see that the pressure exerted by the immense volume of air which surrounds us must be very great indeed. The amount of this pressure is computed to be fifteen pounds to the square inch at the level of the sea. The higher we go from the sea-level, the less dense will the air be, and consequently the less will be the amount of the atmospheric pressure. When travellers climb mountains, or ascend in balloons, they feel the rarity of the air to such an extent, that they find it very difficult to breathe. We shall deal more fully with this subject in our lesson on the barometer. You can easily prove for yourselves that the air exerts great pressure by using what is called a **sucker**. Bore a hole through the centre of a round piece of leather; pass a string through this hole, and fasten it by tying a knot at one end. Soak the leather well in water, and apply it to a stone. On pressing down the leather, the air is driven out from between the sucker and the stone. By means of the string you may then raise the stone and move it about at will, for the leather has firmly adhered to its smooth surface. Its adhesion is caused by the downward pressure of the atmosphere. The pressure of the air can be shown in another way, which we shall now explain.—Otto von Guericke, the inventor of the air-pump,

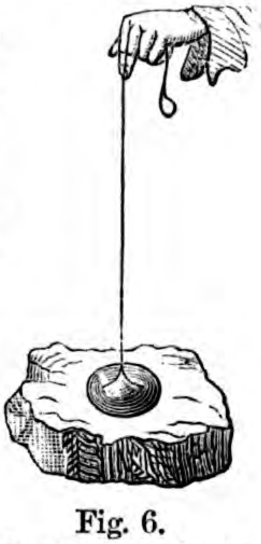


Fig. 6.
Sucker and Stone.

also invented the **Magdeburg hemispheres.** This apparatus consists of two hollow brass or copper hemispheres, the edges of which are made to fit so as to be quite air-tight when in contact. A small tap, T, is affixed to one of them, so that the air can be exhausted, by means of an air-pump, from the globe which they form when placed together (fig. 7). As long as the globe contains air, it is very easy to separate the hemispheres, for the pressure of the air inside is equal to that on the outside. When, however, the air within is entirely exhausted, considerable force is required to separate the hemispheres, owing to the very great pressure of the air on the outside. The hemispheres made by Otto von Guericke were about two feet in internal diameter. Twelve horses, six pulling each way, were required to pull them asunder.

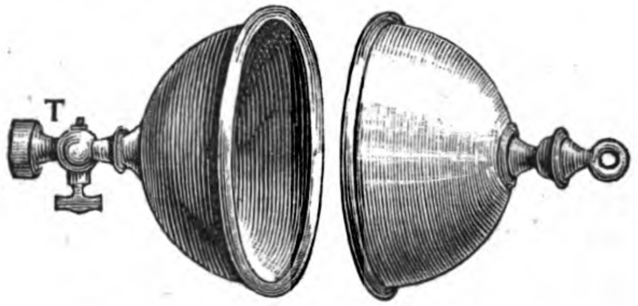


Fig. 7.—Magdeburg Hemispheres.

Here are two simple experiments which you can try:

(1) Fill a tumbler quite full of water, and place a piece of stiff paper over the top of the glass. Now invert it carefully, and you will find that the water will not run out. The upward pressure of the air prevents it from doing so.

(2) Immerse one end of a glass tube in a basin of water, and exhaust part of the air which the tube contains by sucking at the other end. As the air is withdrawn, the water will rise in the tube. If you stop the end of the tube which you have been sucking, by placing your thumb over it, the water will not run out, even though you lift the tube from the basin; but as soon as you remove your thumb, the downward pressure of the air causes the water to flow from the tube.

Compressibility of Gases.—We have already proved that the air is elastic, and that it has weight. It is therefore clear that the lower layers of air are more compressed than those above them. The difficulty in breathing which is experienced in elevated places is owing to this fact. Gases generally admit of very great compression. A large quantity of gas can be forced into a small vessel.

The Specific Gravity of Gases was referred to in a previous lesson, whilst dealing with the specific gravity of liquids. The specific gravity of any gas is proportionate to its density, which of course varies according to the temperature and the pressure to which it is subjected.

CHAPTER V.

RECAPITULATION, DEFINITIONS, ETC.

We will now briefly review the previous lessons. We shall also be able to learn the definitions intelligently, because we now know something about them.

Matter is anything which we can perceive to exist by means of our senses. We have five senses, namely, **sight, hearing, taste, touch**, and **smell.**

All bodies have certain features by which we distinguish them from one another. These distinguishing features we call their **special properties.** Some properties are common to all kinds of matter. The principal of these are **extension, divisibility,** and **weight.**

Extension is that property of matter by which it occupies a certain space.

Divisibility is that property by which matter admits of being broken up into small pieces.

Weight is that property which causes every form of matter to press towards the earth.

A body is a portion of matter whose size is limited. The smallest division of a body which can exist by itself is called a **molecule.** In each molecule there may be many atoms. An **atom** is the smallest possible division of matter.

Matter is found in three states, namely, as **solids, liquids,** and **gases.** In a **solid,** the particles are held closely together, so that the body **retains its size and shape.**

A liquid can easily be made to change its shape, but not its size.

A gas will change both its size and shape.

Liquids and gases have many properties in common, and are sometimes called **fluids.**

We may change the condition of matter, but we cannot destroy it.

Properties of Solids.

Cohesion is that force which binds the various particles of a body together. Cohesion is strong in all solids.

Expansibility is that property by which the particles of matter can be made to take up more room. Solids readily expand when heated.

Compressibility is that property by which bodies are made to occupy less space. All solids possess this property, but solids are very difficult to compress, and transmit pressure only in one direction.

Ductility is that property by which a solid may be drawn out into a wire. Iron is the most ductile metal.

Malleability is that property which enables a body to be hammered or rolled out into a thin sheet without breaking.

Tenacity is the resistance which a solid offers to any force trying to pull its particles asunder.

Hardness is the property by which certain solids resist being scratched or torn.

Elasticity is that force which a body exerts to return to its ordinary shape, from which it has been altered by pressing, stretching, twisting, or bending. A body which exactly regains its shape is said to be **perfectly elastic.** When it has not sufficient elasticity to do this, it is called an **imperfectly elastic** body. An **inelastic body** has no power at all in this respect.

Porosity is that property in virtue of which pores or small spaces exist between the molecules of bodies. All solids are more or less porous, otherwise it would be impossible to compress them. A solid is said to be **brittle** when it will easily snap. When it can be bent in various ways without breaking, it is said to be **tough.**

A rigid body is one which will not easily change its shape, although subjected to great pressure or twisting. Substances which readily yield when pressed are called **soft.** Those which do not easily yield to pressure are called **hard.**

A crystal is a solid having a regular form, and whose molecules are arranged in a definite order.

Crystalline bodies are those composed of crystals, but in which the crystals are so closely united that it is difficult to distinguish them.

Amorphous bodies are those which have no definite shape, and which can be cut easily in any direction.

Fibrous bodies are those composed of fibres or threads.

Granular bodies are composed of little rounded pieces or grains.

An alloy is a mixture of two or more metals. Soft metals, such as gold and silver, are generally alloyed with copper, to harden them.

Gravity is that property which all bodies possess of attracting everything towards themselves.

Properties of Liquids.

The cohesion in liquids is strong enough to prevent the molecules from leaving each other, but is not sufficient to retain them in fixed positions. A liquid will therefore take the shape of the vessel which contains it. Although liquids change their shape, they will not change their size.

Compressibility.—Liquids can only be compressed to a very slight extent. When the pressure is removed, they return to their original size.

Pressure.—By liquids, pressure is transmitted equally in every direction. The pressure increases with the depth.

Liquids tend to keep their surfaces level.—Reservoirs which supply towns with water are placed at an elevation, generally on a hill, and it is on account of the property which the water has of rising to the level of that in the reservoir, that we are enabled to draw water from the pipes which run underground from the reservoir to the taps in our houses.

Buoyancy.—The buoyancy of a liquid is the upward pressure which it exerts on any body placed in it. The quantity of liquid displaced by a body placed in it is exactly equal to the volume of the body. The volume of water displaced by a ship is exactly equal to the volume of that part of the ship which is below the surface of the water. The loss of weight which a body undergoes when placed in a liquid is exactly equal to the weight of the liquid displaced.

By the specific gravity of a liquid, we mean the weight of a certain volume of it as compared with the weight of an equal volume of water. Its specific gravity is proportionate to its density.

Capillarity or capillary attraction is that force by which a liquid will rise through the pores which exist between the particles of a solid.

Change of State in Liquids.—By the application of heat we cause liquids to expand and turn into vapours. Cold will in all cases turn liquids into solids. Ice is a familiar example of a solid formed from a liquid by the action of cold.

Properties of Gases.

Gases have **neither size nor shape** of their own. The particles of gases have **no cohesion.**

Kinds of Gases.—Some gases are easily convertible into liquids, or even solids. These gases are called **vapours.** Some are very difficult to convert, and it is impossible to change the state of others. Gases of the latter kind are called **permanent gases.**

Elasticity.—Gases are very elastic. The elasticity of all gases increases as the volume decreases.

Transmission of Pressure.—Gases, like liquids, transmit pressure equally in all directions.

Pressure of the Air.—At the sea-level the atmospheric pressure is fifteen pounds on the square inch. You will remember that the pressure of the air was proved in the experiments with the sucker, Magdeburg hemispheres, &c. The higher we rise, the less is the density, and, consequently, the less is the pressure of the air.

Compressibility.—Gases admit of very great compression. A large quantity of gas can be forced into a small balloon. All gases are very elastic, and as soon as pressure is removed, they will expand regularly in all directions.

PROPERTIES OF SOLIDS, LIQUIDS, AND GASES.

	SOLIDS.	LIQUIDS.	GASES.
SIZE.	Definite.	Definite.	Indefinite.
SHAPE.	Definite.	Indefinite.	Indefinite.
COHESION.	Strong.	Weak.	Altogether wanting.
COMPRESSIBILITY.	Difficult.	Very difficult and almost impossible.	Easy.
EXPANSION.	Expand when heated.	Expand when heated, and become vapour.	Expand regularly when heated, or when pressure is removed.
CONTRACTION.	Contracted by cold.	Contracted by cold and pressure, and become solids.	Contracted by cold and pressure. Some become solids. Others retain their state.
TRANSMISSION OF PRESSURE.	Transmit pressure in one direction only.	Transmit pressure equally in all directions.	Transmit pressure equally in all directions.

CHAPTER VI.

CONSTRUCTION AND ACTION OF PUMPS—THE BAROMETER.

Pumps.—A pump is a machine for conveying water from a lower to a higher level. Pumps have been used from very early times, but we owe the explanation of their action to Galileo and Torricelli. In this lesson we shall learn how it is that the water rises in pumps. Suppose we take a **syringe** or squirt (fig. 8) and immerse the lower end in water. By drawing up the piston, P, a **vacuum** (empty space) is created below it, and the water at once rushes in to fill it, thus filling the barrel of the syringe. If this were the only contrivance used, we should, in order to discharge the water at a higher level, be compelled to move the syringe. To obviate this, the **common** (suction) **pump** (fig. 9) is used. We will now describe its construction and mode of action. It resembles the syringe in having a barrel and tightly-fitting piston, P. The bottom of the barrel communicates with the water by means of a narrow **suction-pipe,** SP. At the junction of the barrel with the suction-pipe, a **valve,** V, is placed. By a **valve** we mean a little trap-door which opens in one direction only, and which, when closed, will not permit anything to pass through the tube in which the valve is placed. In the piston there is another valve, PV. Both of these valves open upwards, so that the water can only pass in an upward direction. Near the top of the barrel is the **spout,** A. Before the piston is moved, the height of the water in the suction-pipe will correspond with that in the well. At each upward stroke of the piston a vacuum is created in the lower part of the barrel, to fill which, water passes from the well through the suction-pipe. At each downward stroke the lower valve is shut by the water above, which communicates the pressure of the descending piston. Since this water is almost incompressible, it is forced through the piston-valve into the upper part of

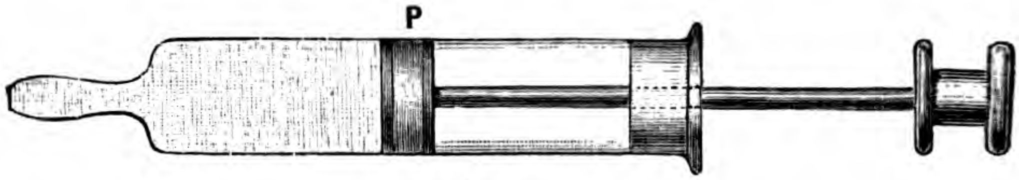


Fig. 8.—The Syringe.

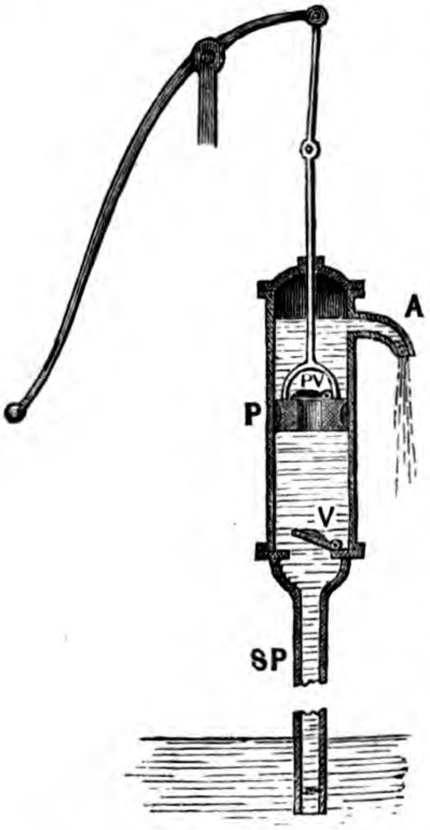


Fig. 9.—Common Pump.

the barrel, and as the piston-valve is closed by each upward stroke, the water accumulates in this upper part until there is sufficient to flow out of the spout. The action of the pump thus clearly depends upon the pressure of the atmosphere, and as this is only just sufficient to support a column of water thirty-three feet high, the suction-pipe must not exceed that length. Unless the pump is well made so that the piston is quite air-tight, the water cannot be raised even to that height. We often find that the packing around the piston shrinks, and so we are unable to raise the water. Water must then be poured **down** the pump to expand this leather packing, and render it air-tight in its action. When this has been done, we can proceed to draw up water.

There is, however, another kind of pump, whose action differs slightly from that of the common pump. In this **force-pump** (fig. 10), as it is called, there is no suction-pipe, and no valve or opening in the piston, so that the water never rises in the barrel above the piston. It has a valve, V, at the bottom of the barrel, like that in the common pump; but in addition, a valve, V′, guards the entrance into a side-tube, T, which opens into the side of the barrel. This valve opens outwards. When the barrel, B, is immersed in the liquid, the water is drawn into the barrel by the raising of the piston, P, as in the previous case, but is forced through the side-valve, V′, into the side-tube at each descending stroke. The force with which the water is driven through this side-tube depends not upon the pressure of the atmosphere, but upon the force which we use to push the piston down. If we use great force, the water can be expelled to a great distance. The fire-engine is a good example of this kind of pump, being practically two force-pumps combined. These pumps work alternately in expelling the water.

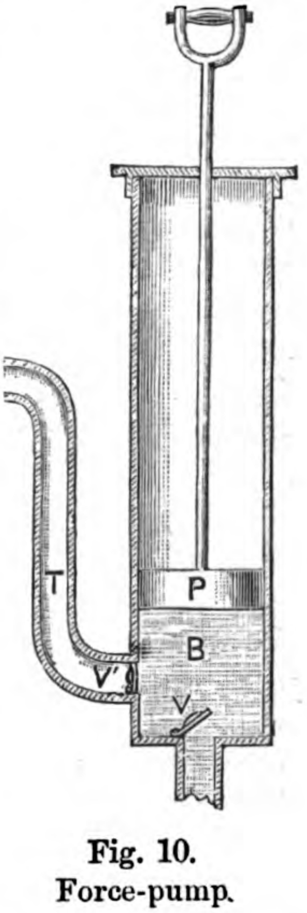


Fig. 10.
Force-pump.

The Siphon.—We have said, in speaking of the upward pressure of the air, that if a tumbler full of water be covered with a piece of stiff paper, and then inverted, the water will not run out; but we cannot keep the water in the inverted glass without the paper. If we take a narrow glass tube closed at one end, and, having filled it with water, invert it in a bowl also containing water, it will remain full of the liquid. If we raise the tube gently out of the water in the bowl, taking care that we keep it upright, the water even then will not flow from it, because the upward pressure of the air on the open end of the tube prevents it. With a wide tube it is more difficult to do this, and with a very wide tube it is impossible. A little thought will show the reason for this. With a glass or wide tube, by using the stiff paper, we keep the surface of the water quite level. Without the paper we cannot do this. No paper is, however, required to keep the surface of the water in the small tube in a level condition. Whilst the surface is level, the air cannot enter, for the water resists it equally in all parts. If we fill a bent tube, having arms of equal length, with water, and, having covered the ends with our fingers, invert the tube, it remains quite full even when we draw away our fingers. This is because the particle of water at A (fig. 11), which is the highest point in the tube, has equal pressure exerted on it by the air pressing on the surfaces at

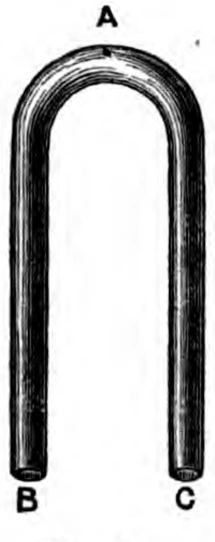


Fig. 11.

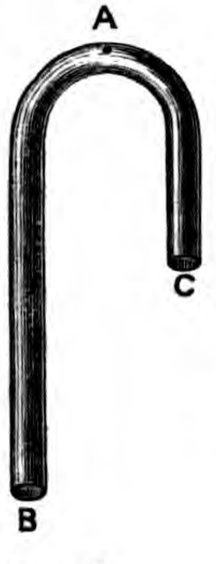


Fig. 12.

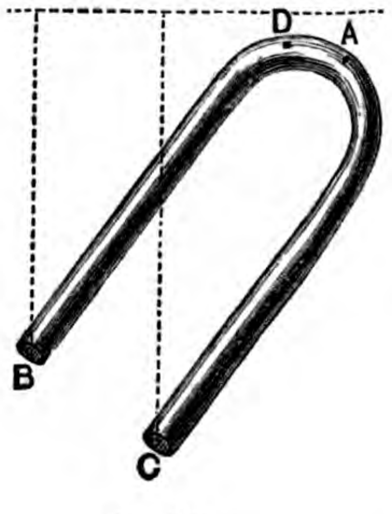


Fig. 13.

B and C, and therefore cannot move. Now, because all the particles of water in the tube are joined by the force of cohesion to this one at A, it follows that if that one cannot move, the others must remain stationary. If, however, the tube have one arm longer than the other, the weight of the water on one side is greater than that on the other, so that the pressure from B to A will be greater in proportion to the volume of water than that from C to A (fig. 12); and, in consequence, the water will be forced down the long arm, AC. If the tube with equal arms be inclined to one side, as in fig. 13, the highest particle of water in the tube is now no longer at A, but at D; and therefore more water has to be supported between C and D than between B and D. Hence the water is forced, as in fig. 12, down the arm, AC. Such an apparatus as this tube forms is called a **siphon. The siphon is used to convey liquids from one vessel at a high level to another at a lower level**, by passing over some elevation between them (fig. 14). For instance, suppose we require to empty a cask of water which is not fitted with a tap, and cannot be moved. By placing the short arm of our tube in the liquid, all the water in the cask may be drawn off as explained in fig. 13. Brewers and dyers usually empty their large vats and tanks in this way. It must always be borne in mind that the short arm of the tube must not exceed thirty-three feet, otherwise the pressure of the air will be insufficient to support the column of liquid within it.

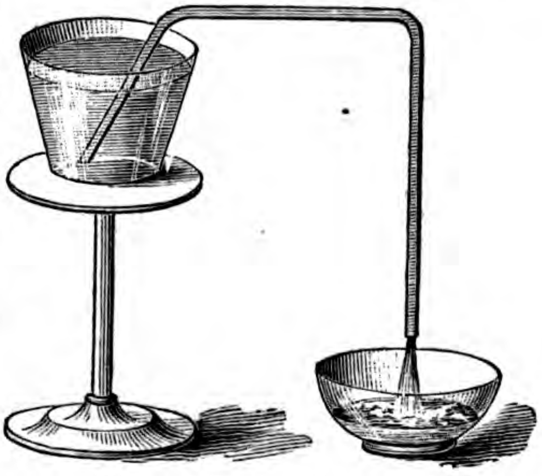


Fig. 14.—The Siphon.

The Air-pump.—In some of our former lessons, reference has been made to taking the air out of a vessel. In this lesson we shall give an explanation of the means and the instrument used for this purpose. In fig. 15, a simple form of air-pump is represented. R is a glass bell-jar called the receiver, standing on the smooth metal plate, S. In the centre of this plate is a small hole, from which the tube, T, runs to the barrel, B. V and V′

are valves both opening outwards. As the piston, P, is drawn out, part of the air escapes from the barrel by the valve, V′. When we push the piston back again towards the far end, this valve instantly closes, so that no air can enter; but more air is expelled from the barrel by the other valve, V. As the air from

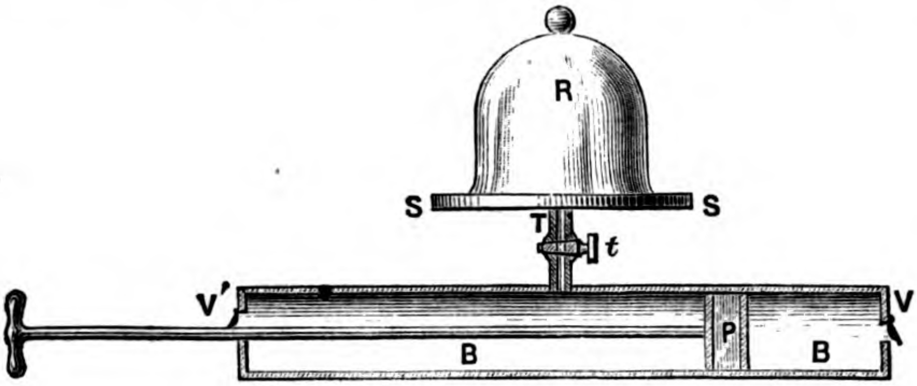
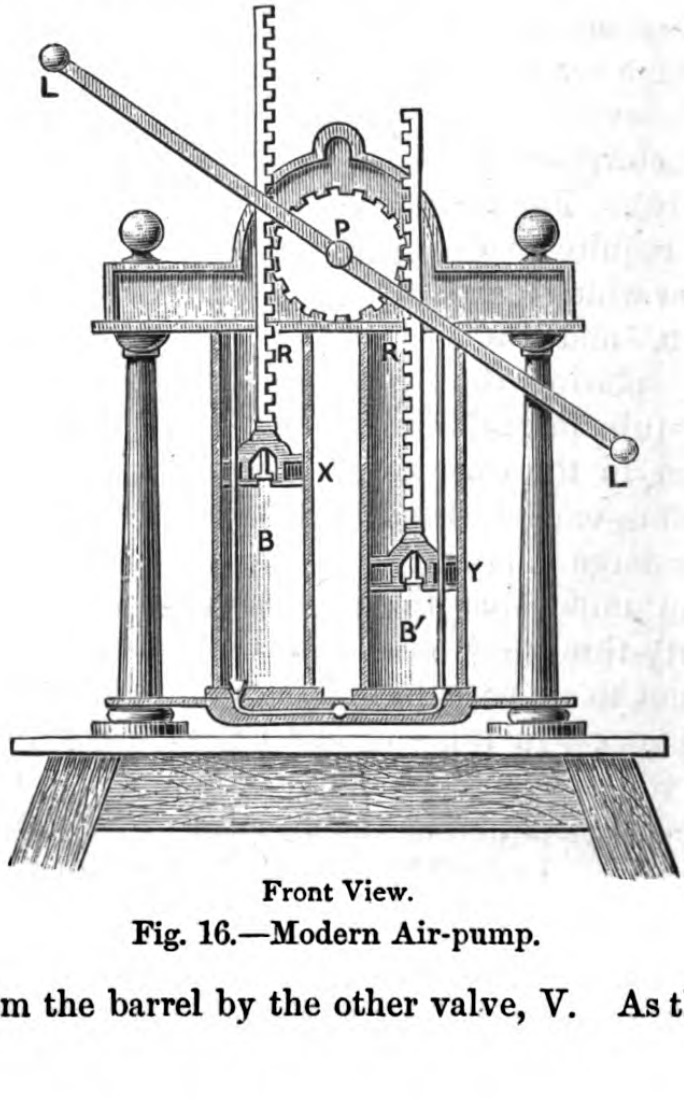


Fig. 15.—Air-pump.



Front View.
Fig. 16.—Modern Air-pump.

the barrel is exhausted, its place is filled by that from the receiver, by passing down the tube, T, so that, by continuing to work the pump, nearly all the inclosed air is withdrawn. When a vacuum has been caused, we cannot remove the receiver from the plate, owing to the pressure of the air on the outside. To liberate the receiver, we let the air in again by means of a tap, *t*, in the tube, T. Some air-pumps have the valve, V′, in the piston like that in a suction-pump, instead of at the end of the barrel, as in our figure. The method of working is, however, the same. Fig. 16 represents the modern form of air-pump. In this there are two barrels, B and B′, which work alternately. The two pistons are worked by means of a pinion, P, and racks, R. The pinion is turned by either a single or double handed lever, L. The diagram shows a double-handed one. In this machine, when one piston, X, ascends, the other, Y, descends, so that air from the receiver presses into one or the other of the pump-barrels at each single stroke. By this arrangement the vacuum is created with half the number of strokes, and consequently half the labour.

A little modification will enable us to utilise the air-pump for charging a vessel with air. In this form it is really a force-pump, the fluid 'air' being used instead of a liquid.

The Barometer.—It has been pointed out, that if we fill a narrow glass tube, closed at one end, with water, and invert it in a vessel filled with the same liquid, the water in the tube will not run out. If, however, we crack or break the glass at the closed end of the tube, the water will at once descend from the tube to the vessel beneath. In the first case, the pressure of the air is exerted only in one direction, namely, on the surface of the water in the lower vessel, and is then sufficient to balance a column of water in the tube. In the second case, the pressure of the air is also directed on the surface of the water at the top of the tube. This pressure counterbalances that on the surface of the water in the lower vessel, and in consequence, the water descends to the same level in the tube as in the other vessel. The pressure of the air at the sea-level has been found to be about fifteen pounds on every square inch. **Torricelli** made many very beautiful experiments to prove the pressure of the air. Instead of using water in the tube, as we have just described, he employed a tube about a yard long, and a quarter of an inch wide, filled with mercury. Having inverted the tube over a vessel also filled with mercury, he found that the mercury descended in the tube until it was only thirty inches high, and then stopped (fig. 17). From this he proved that the pressure of the atmosphere is sufficient to counterbalance a column of mercury thirty inches high. The specific gravity of mercury being thirteen and a half times that of water, it is plain that the atmosphere can support a column of water thirteen and a half times as high as that of mercury, that is, to a height of between thirty-three and thirty-four feet (see lesson on Pumps and Siphon).

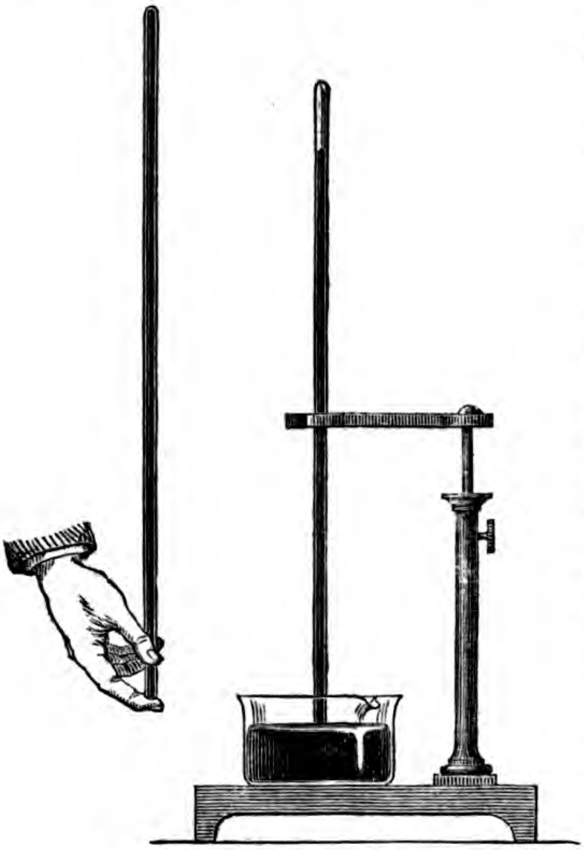


Fig. 17.—Torricelli's Tube.

Another important discovery was made by **Pascal.** He observed, that as he ascended a mountain, the column of mercury decreased in height regularly, and in proportion to the height ascended. In other words, he proved that the higher we ascend the less dense is the atmosphere, and consequently the pressure will counterbalance less weight of mercury.

Mercury is the substance commonly employed in the construction of the **barometer—an instrument to measure the weight of the air.** The tube used by Torricelli represents the simplest form of barometer (fig. 18). For very accurate observations, several precautions have to be taken; for instance:

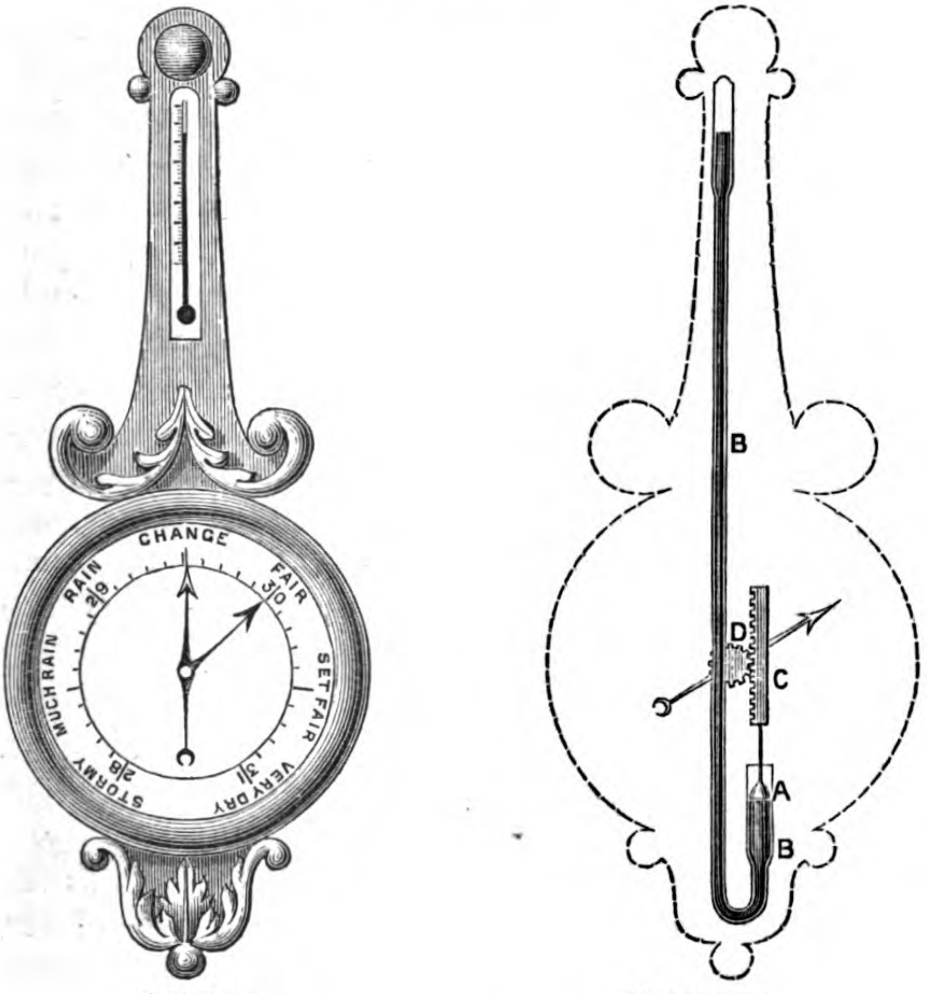
(1) The tube must be of the same diameter throughout.

(2) The mercury must be pure.

(3) When the tube is filled, heat must be applied to get rid of air-bubbles.

(4) The mercury in the vessel below must be adjusted, and when observations are made, allowance must be made for temperature, &c.

The principal uses of the barometer are: (1) To ascertain the heights of mountains, &c.; (2) as a weather-gauge.



(*a*) Front. (*b*) Interior.

Fig. 18.—Wheel Barometer.

(1) **To measure the Heights of Mountains, &c.**—We have said that Pascal found out that the pressure of the atmosphere diminished regularly as he ascended. As the air becomes more rarefied, it can support less weight; and hence the fall of mercury is proportionate to the height ascended. The mercury falls about one inch for every 1000 feet. On the top of Mont Blanc, the mercury stands at about fifteen inches, so that we know that this mountain is about 15,000 feet high.

(2) **As a Weather-glass.**—The use of the barometer as a weather-glass depends upon the fact, that dry air is heavier than moist air. When the mercury falls in the tube, we know that there must be a quantity of vapour in the air, and that we shall therefore be likely to have rain. On the other hand, if the air is dry the mercury rises in the tube, and we may expect dry, fine weather. The barometer is not altogether an accurate instrument in this respect, but any sudden rise or fall certainly indicates a change in the weather. One of the commonest forms of barometer is the **wheel barometer.** A float, A, rests on the surface of the mercury in the tube, B; and rises or falls with the mercury. To this float is attached a rack, C, which turns the hands, which are fixed like those of a clock on a graduated disc, by means of a pinion, D (fig. 18, *b*). In many wheel barometers the float is suspended by a silk thread, the other end of which is fixed to a pulley, on which part of the thread is rolled. Another thread, rolled parallel to the first, supports a weight which balances the float. To the axis of this pulley is fixed a hand, which moves on the disc, like those in fig. 18, *a*. The friction in this kind of barometer renders it useless for very accurate observations.

CHAPTER VII.

MEASUREMENT OF LENGTH, SURFACE, AND VOLUME.

Measurement of Length.—In speaking of the common properties of matter, it was explained that every body must occupy a certain amount of space. To find out how great this amount of space is, we must 'measure,' and in order to do this, we compare the size of one body with that of another. We thus see that 'measurement' is essentially a process of making comparisons. We will first speak of the measurement of length. It is absolutely impossible to find out how long a thing is, without comparing it with some fixed amount or standard which we already know. Let us explain this. Suppose we have two pieces of string. On laying one by the side of the other, we find that they extend either from end to end for equal distances, or that, as we will assume for illustration, one is longer than the other. On measuring the one with the other, we may perhaps find that the greater is three times as long as the lesser. But we do not even now know their lengths. If we were asked how long each was, we could not tell, for we do not know the amount contained by either. To find their lengths, we need some **standard**, that is, some well-known and invariable amount. This standard is sometimes spoken of as the **unit** of measurement, because it is the **one** length, which, being taken several times, will make up the size of some larger body. Our standard or unit of length is the imperial yard. From this all our other measures of length are obtained. Thus, a third part of this yard is called a foot, and $\frac{1}{36}$th part is an inch; whilst 220 of these yards taken together give us the length of a furlong, and 1760 yards, that of a mile. If we knew that the shorter piece of string was one yard, then, since the other was three times that length, we should know that it measured three yards. If the shorter were one foot long, the longer would be three feet or one yard. The yard seems to have been used as a measure even as early as Saxon times; but in very early times, people used to measure by the lengths of various parts of their bodies, as the **palm**, **span**, **cubit**, &c. Of course, these parts were longer in some people than in others, so that these measures were not always the same, and could not be very closely depended on. To prevent dishonesty, which would arise from the use of measures which differed in length, parliament ordered metal bars of the standard length to be made and set up in various towns, and compelled people to adopt their size in all their dealings. You will say, perhaps, that these bars would be longer in summer than in winter, and that the yard would be shortest in cold weather. This is quite true; but in order that the standard should not vary, the measurement of the bar has to be taken at a given temperature (62° Fahrenheit).

Measurement of Surface.—All bodies possess breadth to some extent, as well as length. A line made on a slate with your pencil has some breadth or width, but we usually consider its length only. The width of a piece of tape is more clearly seen, whilst that of the floor is quite as evident as its length. Width is measured by the same standard or unit as length. By considering the length and breadth of a body, we are enabled to find the measurement of its surface or area, as we call it. To do this, we think of its surface as being divided into squares of equal size, and find its area by counting the number of these squares. A square with its sides each one yard long is called a square yard. In like manner, one with its sides a foot long is a square foot; whilst one whose sides measure one inch is a square inch. Suppose we wish to find the area of a box lid which is four feet long and three feet wide. If the lid be divided into squares, each having sides a foot long, four squares placed in a row would just reach from one end to the other, whilst three of these rows can be placed from front to back (see fig. 19). Thus, it is plain that there are twelve squares altogether, each of which, as we have said, is a square foot. The area of the box lid is therefore twelve square feet. The **rule to find the area of any surface**, then, is—multiply the number of units in the length by the number in the breadth, and the product will be the area or number of square units.

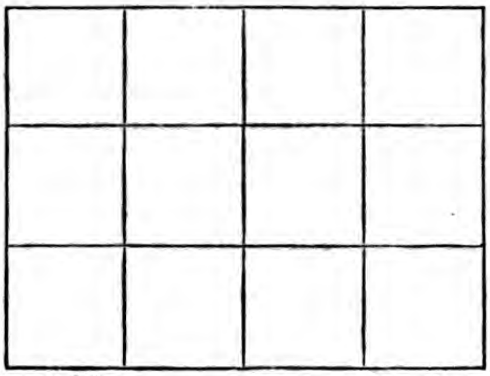


Fig. 19.
Area, 4 × 3 = 12 square feet.

Measurement of Volume.—To find the size of a parcel or of a block of stone which would just fill the box, we must know the length, breadth, and thickness or depth of the block, or the inside measurements of the box. The size of a body found by using these three dimensions is called its **volume** or **contents**. In order to find this, we think of the body as being divided into cubes of equal size. Now every face of a cube is a square (fig. 20). The sides of all these squares must be equal. A cube having a side one yard long, or having a face which measures a square yard, has a volume of one cubic yard. In like manner, a cube having faces measuring one square foot or edges one foot long has a volume of one cubic foot, whilst one cubic inch is the volume of a cube having edges one inch long and faces of one square inch. Suppose our block of stone to be four feet long, three feet broad, and

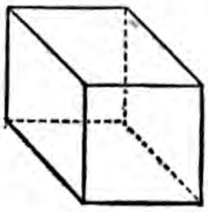


Fig. 20.
A Cube.

two feet thick (fig. 21). Now, twelve of these cubes would just stand on the bottom of the box, and twice this number will fill the box, since it is only two feet deep. There are, therefore, 12 × 2 = 24 cubes in all, and since each cube is a foot in volume, the whole volume of the block is 24 cubic feet. Thus, **to find the volume of any body**, multiply the number of units in the length, the breadth, and the thickness or depth together, and the product will be the number of cubic units in the volume. Thus, in the example taken above, 4 × 3 × 2 = 24, which will be the number of cubic feet in the block. If the body be of irregular shape, it is very difficult to find its volume.

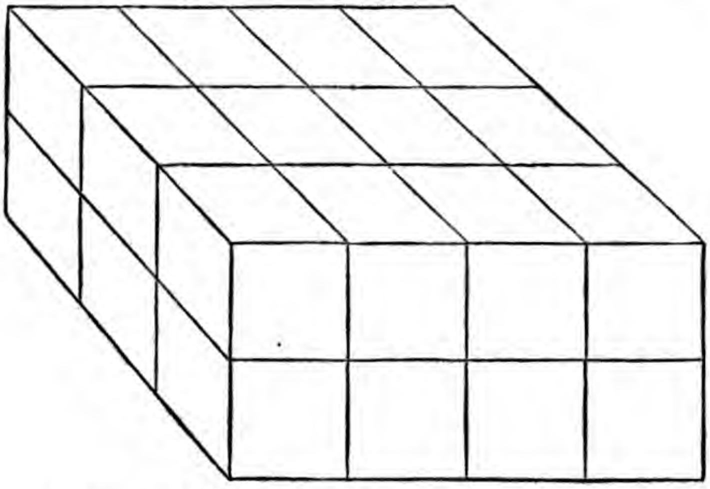


Fig. 21.—Volume, 4 × 3 × 2 = 24 cubic feet.

Liquid Measure.—The volumes of liquids and of certain dry solids like flour, corn, potatoes, &c. are ascertained by the use of measures of capacity. The **imperial gallon is our standard of capacity.** For small quantities we use the half-pint, pint, quart, or half-gallon measures; while for large quantities, the peck and bushel are employed. All weights and measures are now uniform in all parts of the country. This desirable end was attained by the passing of the 'Weights and Measures Act,' by which the standards were fixed.

Workmen's Tools for Measurement—Rules.—For the purpose of measurement, workmen usually carry **rules**, or thin strips of wood hinged together. Some rules are two feet long, others three, whilst a few are four feet in length. These rules are divided into feet, inches, and fractions of an inch. **Compasses** (fig. 22).—For measuring small distances, compasses are used; whilst **calipers** (fig. 23) are employed to ascertain the diameter of spheres, balls, and other round bodies. **Chain.**—In measuring land the chain is used. A chain is twenty-two yards long, and contains one hundred links. Ten chains make a furlong, and eighty chains a mile.

Fig. 22.—Compasses.

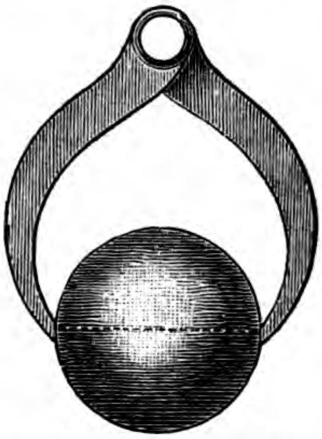


Fig. 23.—Calipers and Sphere.

CHAPTER VIII.

MEASUREMENT OF TIME AND VELOCITY.

Measurement of Time.—When a farmer sows wheat in his field, he does not expect to reap the harvest at once; he knows that he must wait for the corn to grow and ripen. The interval which there must necessarily be between the sowing and the reaping may be generally defined as a **space of time.**

We always think of time as of something which is passing regularly away, and which cannot be recalled. Time, like everything else, must be measured by means of some 'standard.' By means of this standard, both the rate at which time is passing away, and the amount which has elapsed since some by-gone event, may be ascertained. It might be deemed advisable to use the time which elapsed between one sunrise and the next as the standard; but the length of this period varies with the season of the year, for in the first part (January to June) the sun rises a little earlier each day; whilst during the remainder of the year, the time of sunrise is a little later every day. The periods of darkness and of daylight are exactly equal in only two days during the whole year—namely, at the spring (March 21st) and autumnal **equinoxes** (September 21st). The most convenient standard is the **solar day**, which is the time taken by the earth to rotate once on its own axis. In other words, a solar day is the time between noon—the instant at which the sun is exactly south—on one day and the noon of the next day, when it next occupies exactly the same position. This time is divided into twenty-four equal parts, called **hours.** Each hour is subdivided into sixty equal parts called **minutes**, and every minute contains sixty **seconds.** A **month** is the time which elapses between one new moon and the next. This is twenty-nine and a half days—the period taken by the moon to make one complete revolution of the earth. We, however, reckon twenty-eight days as a lunar month.

A **year** is the period in which the earth revolves once round the sun. In making one of these revolutions, the earth rotates on its axis nearly 365¼ times, so that a year contains nearly 365¼ days. We reckon 365 days as a year; but as the quarter of a day which we lose annually amounts in four years to one whole day, every fourth year has 366 days. This is called a **leap-year.** A year contains twelve **calendar months** of unequal lengths.

How to compute Time.—If we were able to set up a pole in a field so that the sun would always shine on it, we should notice

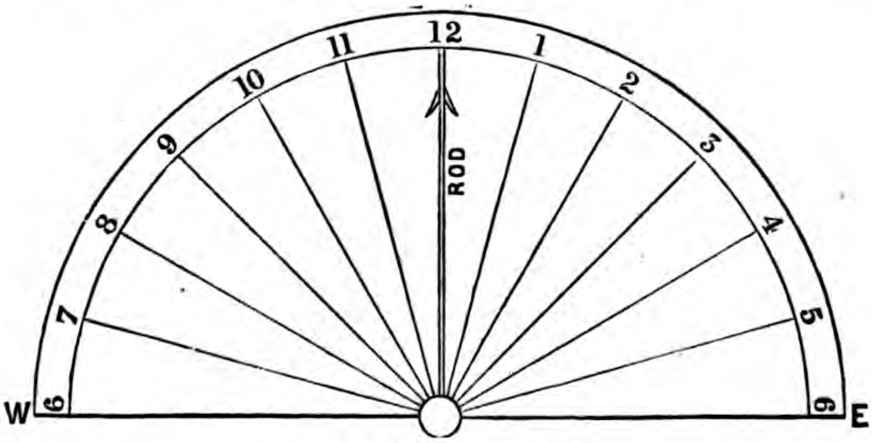


Fig. 24.—Sun-dial.

that the shadow cast by the sun would make a complete circle round it once every solar day. Now, since it is light for only half the solar day, the shadow can make but half a circle. As the whole circle or solar day contained twenty-four hours, the half-circle will only contain twelve; so that by dividing this into twelve equal parts, we can see over what distance the shadow will pass each hour. An instrument for computing time in this way is called a **sun-dial** (fig. 24). In making a sun-dial, care must be taken to have the twelve spaces equal, and also the pole pointing exactly to the North Star, in order that when the sun is due south the position of the shadow shall be due north. It will be in this position at noon or mid-day (twelve o'clock). At six in the evening, the shadow will fall on the eastern point (6 E.); while at six in the morning, it will fall due west (6 W.); and on the intermediate spaces, at the times marked in fig. 23. By subdividing these spaces, we may compute halves and quarters of an hour. Sun-dials can only be used, of course, when the sun shines, for only then can a shadow be seen.

Various other methods have been employed to measure time. We read of Alfred the Great counting the time by burning **wax-candles** twelve inches in length. Each candle was made large enough to last four hours, and was divided into four parts, each of which burned for an hour. Then, again, **sand-glasses**, or egg-boilers as we now call them, were used for the purpose of reckoning time. These were formerly much larger, and contained just as much sand as would pass from one end to the other in one hour; hence they were called **hour-glasses.**

Water-clocks were used in very early times. They consisted of a tube containing water, a float free to move upwards or downwards in the tube according to the quantity of water, and a string, one end of which was fastened to the float, the other being attached to and partly wound round a wheel. This wheel was placed at the back of a round card, divided, like the dial-plate of a clock, into twelve equal parts. Hands were attached to the axis on which the wheel turned. These moved round as the float sank in the tube, and unwound the string. To cause this float to sink, a regular and constant stream of water was drawn out of the tube. Of course, this water had to be replaced when the tube became empty.

We will now consider our present method of computing time —namely, by **clocks and watches.**

The regular motion of the clock is insured by the use of the pendulum, which swings so accurately from side to side. Let us examine the works of a clock, and see how this regular working is kept up. Connected with the top of the pendulum is a curved bar, having at its ends little teeth-like projections called pallets (B). These pallets are so arranged, that either one or the other is always caught between the teeth or cogs of a wheel called the escapement wheel (A). This wheel is turned by a weight attached to a chain or cord wound round the axle of the lowest one of a series of wheels (see fig. 25). As the pendulum swings, one pallet is lifted from between the cogs, and the wheel escapes from the confinement in which it was held by the pallet; the weight descends, and causes the wheel to turn until it is stopped by the other pallet fitting between the cogs on the opposite side. When the pendulum swings back again, the second pallet is raised, and the first is again caught between the cogs. You thus see that the wheel is turned and stopped alternately by the action of the pendulum. This accurate movement is communicated to the hands, and thus time is recorded.

In order that a clock may keep good time, its pendulum must always be the same length. A short pendulum swings more rapidly than a long one. From this we see that if a clock loses, we must shorten the pendulum to make it go faster; and if a clock gains, we lengthen the pendulum to make it go slower. A pendulum which is a little more than thirty-nine inches long, swings once every second.

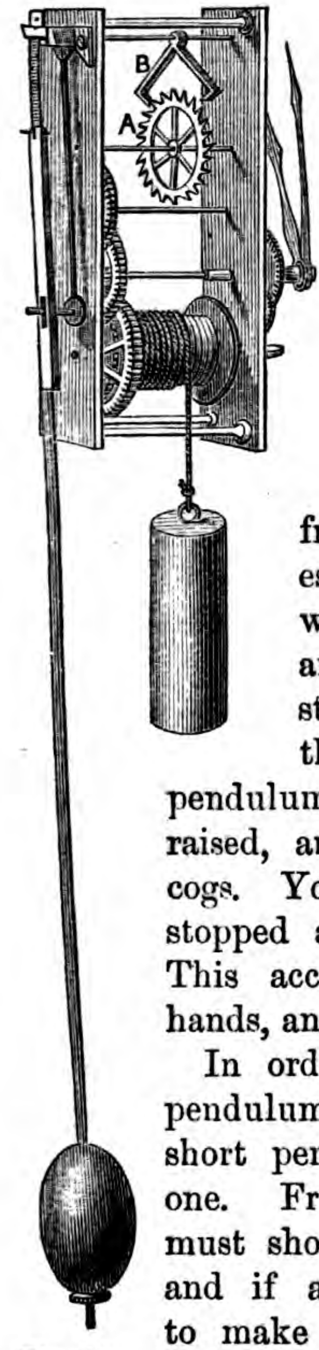


Fig. 25.
Pendulum.

The principle involved in the working of a watch is exactly the same as that in the clock. Instead of a pendulum, however, the watch has a balance wheel.

Measurement of Velocity.—A body will remain at rest if not acted on by force. A body is said to **move** when it changes its position at different times. When once a body is set in motion, it will continue to move in a straight line, unless its course is stopped or changed by some opposing force. The great forces which impede a body in motion are **gravity, resistance of the air,** and **friction.** The inability which all matter has, either to move or to stop moving, as the case may be, unless acted upon by a force, is called **inertia.** Motion always involves the consideration of two things, namely, **space** and **time.** We have already learned to measure the distance over which a body would move in a straight line; but if we wish to compare the motion of one body with that of another, we must also consider the time taken by each body to travel a certain distance. We call this the **velocity** of these bodies.

Velocity may be defined as the measurement of motion, and represents the distance traversed by a body in a given time. Now, as we have seen in considering measures of length, space, and time, we must first of all decide upon a certain **standard** or **unit** of measurement. The standard or unit for velocity is the **number of feet traversed per second.** Let us compare the velocities of two bodies, one of which moves at the rate of 120 yards per minute, while the other travels at the rate of thirty feet per second. Now, we must first find how many feet each will pass over in a second:

No. of yards passed over in 60 seconds by the first body $= 120$.
∴ " " 1 second " $= \frac{120}{60} = 2$.
∴ No. of feet per second passed over " $= 2 \times 3 = 6$.

Now, the second body passes over thirty feet per second. Hence, we say the velocity of the second body is greater than that of the first; in fact, it is five times as great.

Velocity may be either **uniform** or **variable.**

Uniform Velocity.—The velocity of a body is uniform when it passes over equal distances in equal portions of time. Thus, the hands of a clock move uniformly.

Variable Velocity.—The velocity of a body is said to be variable when it passes over unequal distances in equal portions of time. For example, if a body moves at the rate of three feet the first second, four the second, five the third, &c., we say the velocity is variable ; and because it increases in speed, we say its velocity is **accelerated.** If, on the other hand, the body moves three feet the first second, two feet the second, &c., we say its velocity is **retarded.** As a rule, we shall only have to deal with uniform velocity. Light travels with a velocity of 190,000 miles per second. You will readily see that in such a case as this, it would be very inconvenient to express the velocity as so many **feet** per second. Again, we know that sound travels at the rate of 1120 feet in a second. Having these data given us, we can easily estimate the distance from us at which, during a thunderstorm, the flashes of lightning occur. For instance, suppose that we hear the sound of the thunder five seconds after seeing the lightning-flash. We know that the flash of the lightning and the sound of the thunder start at the same time. Now, we also know that sound travels at the rate of 1120 feet per second, $\therefore$ the distance $=$ velocity $\times$ time $= 1120$ feet $\times 5 = 5600$ feet. By this means we are able to calculate the velocity of a cannon-ball.

In ordinary calculations, we generally take the average velocity of any body. For instance, suppose we want to compare the velocities of two trains, one of which travels from Swindon to Paddington (77 miles) in two hours, and the other from Swindon to Swansea (140 miles) in four hours. Here we first find the average velocity of each train per hour.

In the first case, the average velocity is $\frac{77}{2} = 38\frac{1}{2}$ miles.
" second " " $\frac{140}{4} = 35$ "

Hence, their rates are as 35 to $38\frac{1}{2}$, or 70 to 77 ; and we say the velocity of the former is greater than that of the latter.

CHAPTER IX.

RECAPITULATION.

We will here gather together the chief points in the last three chapters.

Common Pump.—The atmosphere at the sea-level will balance a column of water nearly thirty-four feet high. On this principle depends the action of our common pump. **Pumps** have been used from the earliest times, but their action has only been understood since the time of Torricelli.

A force-pump is used when we wish to force water to a great height. Unlike the common suction-pump, it has a solid piston, the water being driven out of the barrel by means of a side-tube, the entrance to which is guarded by a valve. Fire-engines are good examples of force-pumps.

A siphon is a vessel in the form of a bent tube, having one arm longer than the other, and is used to convey liquids from one vessel to another by passing over some elevation lying between them. The vessel from which the water is drawn is situated at a higher level than the other. The short arm of the siphon must not exceed thirty-two feet in height, or the pressure of the air would be insufficient to support the volume of water contained in it. The air must be drawn off from the short tube before the siphon can be used.

A valve is a little trap-door opening in only one direction. When closed, it fits very tightly over the aperture which it is intended to cover.

The air-pump is an instrument used for exhausting the air from a vessel. It was invented in 1650 by **Otto von Guericke,** Burgomaster of Magdeburg in Germany.

The barometer is an instrument which is used for measuring the pressure of the atmosphere. **Torricelli** made the discovery that the pressure of the air at the sea-level would support a column of mercury thirty inches high. The action of barometers depends entirely on this principle. Barometers are used as weather-gauges. Dry air is heavier than moist air, so that when the atmosphere is dry and clear, the mercury stands high in the tube. On the other hand, it will sink in the tube when the air is moist, because the pressure of the atmosphere is not so great. Hence, when the mercury stands high, we say we shall have fine weather ; and when it goes down, we expect rain.

Pascal discovered that the atmosphere becomes less dense as we ascend a mountain. Owing to this fact, barometers are used in measuring the heights of mountains. The mercury falls one inch for every thousand feet ascended.

Measurement.—Mechanics take the dimensions of bodies either with regard to their **length (linear)**, their **area (superficial)**, or their **volume (cubical)**. In all measures, we must first fix a standard.

The standard for measurement of length is the **imperial yard.** Metal rods of the standard length are preserved in various parts of the country, by order of the government. A third of the length is a **foot**, and $\frac{1}{36}$th part is an **inch.** To prevent any error either from expansion or contraction, the rods are measured at a temperature of 62° Fahrenheit.

The standard for measurement of surfaces is the **square yard. To find the area of any surface, you multiply the length by the breadth.**

The standard for measurement of volume is the **cubic yard. To find the volume of a body, you multiply the length, breadth, and height together.**

The standard for measurement of time is the **solar day,** the length of which is the time taken by the earth to complete one revolution on its own axis. We divide the day into twenty-four equal parts called **hours.** The hours are further divided into sixty equal parts called **minutes,** and the minutes are subdivided into sixty equal parts called **seconds.** The time taken by the moon to make a revolution round the earth is about **twenty-nine and a half days, or a month.** The earth revolves once round the sun in a little more than 365 days, or a **year. Every fourth year has 366 days.** Instruments for measuring time are : (1) **Sun-dial** ; (2) **sand-glass** ; (3) **clocks and watches.**

Motion.—A body is said to move when it changes its position, or when it occupies different positions in different periods of time.

Inertia is the inability of any body to change its state of rest or motion.

Velocity is the measurement of motion. In order to measure the motion of bodies, we must take into consideration both the distance travelled and the time. By the velocity of a body, we mean the distance which it passes over in a given time.

Velocity may be Variable or Uniform.—It is uniform when the body passes over equal distances in equal portions of time. It is variable when it moves at different rates over equal distances. When the motion increases, as in a stone falling to the ground, we say the velocity is **accelerated.** On the other hand, when the motion decreases, as in the case of a ball rolling along the floor, the velocity is said to be **retarded.**

The **unit of measurement** for velocity is the **number of feet per second.** Sound travels at the rate of 1120 feet per second, and light at the rate of 190,000 miles per second.

CHAPTER X.

APPLICATIONS OF THE PROPERTIES OF MATTER AS EXEMPLIFIED IN A FEW OF OUR COMMON INDUSTRIES.

In this chapter, we propose to show how a practical knowledge of the different properties which we have been considering can be made to bear on some of our more common occupations, and how useful such knowledge may become in the practical work of every-day life. An intelligent knowledge of the properties of the materials used in our occupations will considerably improve the quality of the work, and will prevent many mistakes.

IRON.

As being the king of metals, and as possessing nearly all the properties of solids, we will first consider the great **iron industry.** The utility of iron is seen in the almost innumerable articles manufactured from it. By means of it the earth is cultivated, towns and cities have been built, and without it very few of the arts could be practised.

Where found.—Iron is found in great abundance in this country, especially in the districts where coal is most abundant, namely, in **Durham, Yorkshire, Lancashire, Staffordshire**; in **South Wales**; and in **Lanarkshire, Scotland.** In all these districts, large works are erected, and thousands of hands are employed in the manufacture. In its raw state, the iron is found mixed with other substances, such as sulphur, clay, &c.

Preparation.—The iron ore is first roasted in a kiln, in order to separate the sulphur from the iron; it is then mixed with coal or coke and limestone, and the whole is placed in large conical-shaped furnaces. Intense heat is then applied until the mixture becomes melted. The lime, clay, and flint unite together and form slag, whilst the iron sinks to the lower part of the furnace. When sufficient iron has in this way been brought to the bottom of the furnace, it is let out by the workman through a hole which has until now been stopped up. In this state the metal is known as **pig-iron.** It is also called **cast-iron,** because it can be readily moulded into any shape.

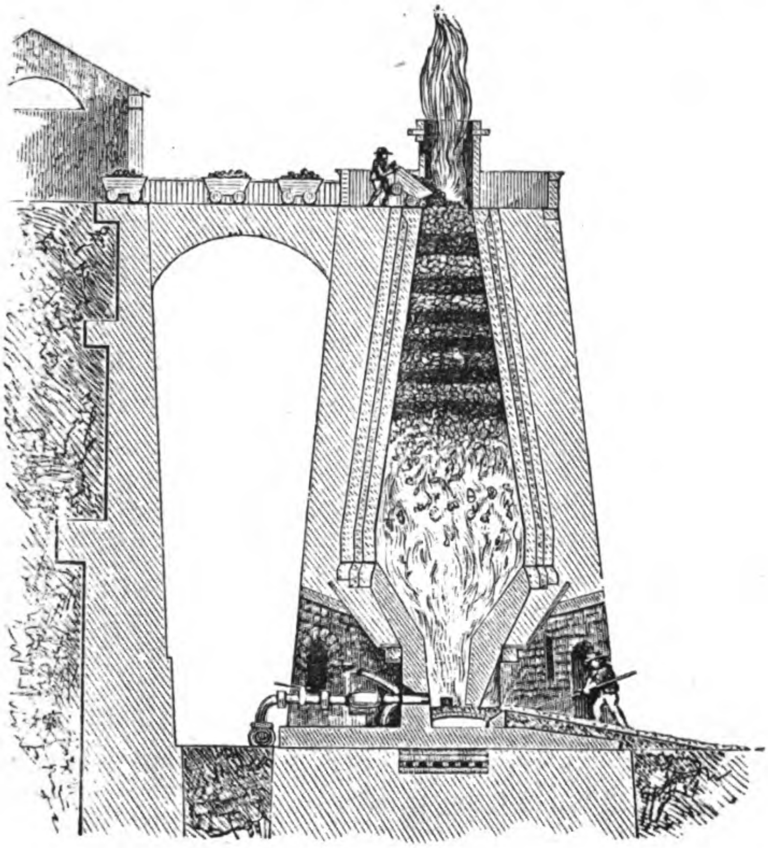


Fig. 26.—Blast-furnace.

Properties of Cast-iron.—It is easily **fusible,** very **hard** and

brittle, and **its power to resist pressure is almost unlimited.** Its principal uses are for fire-grates, water-pipes, railings, ovens, &c. Cast-iron columns are frequently used as supports for the roofs of large buildings, owing to their great strength for resisting downward pressure.

Manufacture of Wrought-iron.—The next process is to free the iron from the carbon. This is done by refining it in another furnace, in which the fire is separated from the metal by a low partition or bridge. By this arrangement the flames are conducted over the surface of the metal, creating an intense heat. So great is the heat in the **puddling** furnace, that a stream of water or air is kept circulating around it, to protect the materials of which it is composed. The puddler works through a door opening on to the molten iron, and his work is to stir up the metal, so that every particle of it shall be exposed to the action of the oxygen passing over it from the fire, and thus burn out all impurities. With an iron tool, called a rabble, he collects the metal into **balls or blooms.** These are taken out and beaten whilst at this great heat with **steam-hammers,** and are afterwards passed between rollers, decreasing in size. The metal is now cut into convenient sizes, and is called **wrought-iron.**

Sheet-iron is made by passing the metal between smooth rollers without grooves. The rollers are gradually screwed together until the required thickness is reached.

Properties of Wrought-iron.—It is **not easily fusible,** but is **very malleable** when heated to a glow. In this state, too, it can be **easily welded,** so that two pieces of wrought-iron can be hammered together into one mass. It also possesses the property of **ductility** to a surprising degree, and may be drawn out into a wire finer than a human hair. In **tenacity** and **strength,** wrought-iron surpasses any other metal. By being heated, and then suddenly cooled, wrought-iron can be made very hard. Owing to these properties, it is used wherever great strength is required. Chains, machinery of every description, rods for suspension bridges, &c. are made of wrought-iron. All the articles manufactured by the blacksmith are exclusively of wrought-iron.

Steel.—During the last few years, owing to the discovery by Sir

Henry Bessemer of a new method of manufacturing steel, the old method has almost been discarded. By the old system, the best wrought-iron was buried in charcoal, and heated for several days without being exposed to the air. In this process it became whiter in colour, and exceedingly hard and blistered. To prepare for use, the bars were again heated and hammered together. By melting in crucibles, cast-steel was prepared.

What is termed steel is iron with a small proportion of carbon in it. By the Bessemer process, puddling is dispensed with. The crude iron is poured from the smelting-furnace into the **converter**, and the sulphur, carbon, and silicon are burned out by passing a blast of atmospheric air through the molten metal. To the wrought-iron thus prepared, a sufficient quantity of **carbon is added** to convert the whole mass into steel. In this way, ten tons of cast-iron may be converted into cast-steel in less than thirty minutes after being melted, and at a very small expenditure of fuel.

Properties of Steel.—Steel combines the malleability of wrought-iron with the fusibility of cast-iron. By differences in tempering, a brittle penknife or a delicate watch-spring can be manufactured from it. Steel, if heated to redness and allowed to cool, becomes **soft** and **pliable.** If, however, again heated and suddenly cooled, it becomes very **hard**, and is rendered **capable of being highly polished.** Steel is used for all cutting-instruments. When made into tools which are moved by machinery, steel is used for cutting and planing iron. Properly tempered, it is made into springs for clocks, watches, carriages, &c. For this purpose, great **elasticity** is required.

In a magnetised form, steel is used in the construction of the mariner's compass.

To sum up—iron is the most useful of all metals, and possesses the greatest variety of properties. In one state (**cast-iron**), it is as **brittle** as glass ; in another (**wrought-iron**), it is the **toughest of all bodies.** In the first state, it is readily **fusible** ; in the second, it is one of the most **infusible** of metals. **Some kinds of iron are perfectly elastic** (**steel**), while **others are totally inelastic.** Iron and steel tools of extraordinary hardness cut sheet-iron as readily as an ordinary knife will cut wood. **Wrought-iron is very malleable, and is so ductile** that it can be drawn out into a very fine wire.

Magnets, and the needle of the mariner's compass, are made from magnetised steel.

The manufacture of iron is typical of all the other metal manufactures. In all cases, heat is required to separate the metal from the impurities in the ore.

GLASS.

The manufacture of this substance is well worthy of our consideration. Glass is made of sand or flint combined with some alkaline substance, such as **soda**, **potash**, &c. These materials are mixed in proper proportions, and are placed in a furnace and moderately heated until fusion takes place. This operation is termed **fritting**. After this, large vessels are filled with the **frit** and subjected to intense heat, in large dome-shaped furnaces, until perfectly fused. The scum which rises to the top of the molten mass is from time to time removed. The material is now in a plastic state, and may be moulded or blown into any shape desired by the workman, who dips one end of a tube into the crucible, and by carefully turning the tube, collects as much glass, in the form of a ball at the end, as he requires for the article he is about to make. He then applies his mouth to the opposite end of the tube, and blows the glass either in a mould, or into the form of a large hollow globe. A stick is then attached to the opposite side of the globe, which, after being separated from the tube, is heated and twirled round in the same manner as a mop is twirled to drive off the moisture. By this process, the globe is converted into a flat disc, circular in form. From this disc, sheets of glass for window-panes, &c. are cut.

There are several kinds of glass made, namely, **common and bottle glass**, from which coarse articles, bottles, &c. are fashioned; **crown-glass**, from which window-panes are cut; **plate-glass**, which is the purest and best, and of which the more expensive articles are manufactured. Plate-glass is not blown, but cast. When melted, it is poured on a large smooth iron table, and heavy metal rollers are passed over it, to make its upper surface level. These plates are, when cooled, polished with emery, &c. Great care must be taken that the glass in its heated state is not exposed to cold, or the articles will fall to pieces, as though struck with a hammer. The cooling process is called **annealing**, and is carried out as follows: the articles are placed in a very hot furnace, the heat of which is lessened gradually, so that several days must elapse before it gets quite cold.

Now let us consider the properties of glass.

In the first process, you see that heat turned the solids into a liquid; then in the second process, the substance is by more perfect fusion rendered plastic and ductile, so that it can be made to assume any shape; while in the 'annealing' process, it becomes hard, transparent, and fit for use. In a solid state, it is almost free from porosity. It possesses a lustre from which we call it **vitreous.** It cannot be dissolved or corroded by substances in common use, or even by the strongest acids. It is very brittle; and yet in the form of thin threads, it possesses a great amount of elasticity.

SALT.

Salt occurs either as a mineral in beds or layers, as in the salt mines of Cheshire and Poland, or it is obtained from salt springs or sea-water by the process of **evaporation.** When found in a pure state, rock-salt is colourless and transparent. Frequently, however, it contains earthy impurities. These are removed by dissolving it in water, filtering to separate the impurities, and then evaporating the liquid. Rock-salt is a crystalline body, the crystals having the form of cubes. Salt is readily dissolved in hot or cold water. It is worth noticing that heat does not materially assist the rapidity with which it dissolves, or the quantity dissolved.

To prepare salt from sea-water, it is only necessary to apply heat so as to evaporate the water. The evaporation may either be spontaneous by the heat of the sun, or the water may be mechanically boiled away. It is important to notice that when evaporation takes place, the vapour given off is that of perfectly pure water. Nothing solid can be thus driven off. Hence distilled liquids are the purest. After evaporation, the salt is left in the form of crystals. About three parts in every hundred of sea-water are salt.

Owing to its great preserving properties, salt is extensively used, and the manufacture of it by evaporation is fast becoming an important branch of trade.

WATER—HYDROSTATIC PRESS.

Let us now illustrate the properties of liquids by the consideration of water as a motor-power.

Water has long been used for turning mills, &c.; but its use is not so extensive as its many properties might warrant. In this lesson we wish to speak of one machine only, namely, the Hydrostatic Press. It has been pointed out in a former lesson that water will rise to the same level in both arms of a bent tube. If pressure be applied to the surface of the liquid in one of these arms, the liquid will rise to a higher level in the other arm, unless an equal pressure is used there to keep it down. Thus, if six-pound pressure be used in one arm, we must, in order to maintain the level, apply a like weight in the other. In tubes with arms of unequal size, **the pressure required is proportionate to the surface of the liquid in each arm.** From the knowledge of this fact, a most important invention was made by Mr Bramah in 1796. It is a machine known as the **Hydrostatic or Bramah's Press.** A glance at fig. 27 will explain its principle.

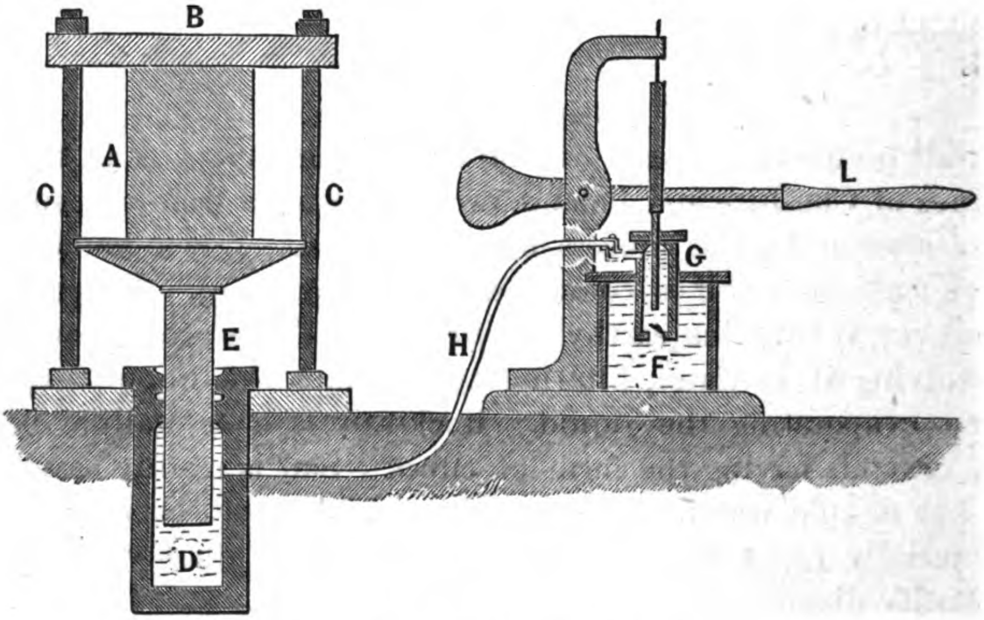


Fig. 27.—Hydrostatic Press.

A is a body which we require to compress. B is a stout iron plate fixed to, and supported by, iron pillars, C. D is a large cylinder, and on the surface of the water it contains is the piston, E. F is a smaller cylinder, and G an air-tight piston fitted in it. H is a small tube, through which the water can pass from one cylinder to the other. When weight is applied to the piston, G, by means of the lever, L, the water is forced through the tube, H, into the cylinder, D, and raises the piston, E. As this piston is forced upwards, the body, A, is compressed by being crushed against the plate, B. **If the surface of the liquid in D is 100 times as great as that in F, a hundredweight placed on the piston, G, will force up the piston, E, with a force of 100 cwts., or five tons.**

The chief purposes for which the hydrostatic press is employed are: compressing paper and packing it into parcels and bales; pressing linen, wool, &c. In iron-works, the nuts and washers are punched out, and even boilers have been riveted, by the use of this machine.

STEAM.

Having treated of water as a motor-power, we must now speak of the importance of steam in this respect. When heat is applied to a lump of ice, the temperature is soon raised to 0° C. or 32° above 0° F. From this point we cannot raise the temperature, no matter how much heat we may apply, until the whole of the ice is melted. When this is accomplished, the water will increase in temperature until it reaches what we call the boiling-point at 100° C. or 212° F. After this, however much heat we may apply, and however long, we cannot make the water any hotter than 100° C. Any additional heat will change the water into vapour or steam. Now, it is this steam, the use of which has almost revolutionised the world, that we want to speak about.

The question of utilising steam puzzled men of science for many generations. The **Marquis of Worcester** discovered the power of steam whilst in prison in the Tower; but it was many years before any practical use was made of this great power. Perhaps the names which will most readily occur to you as the great utilisers of steam are **Watt** and **Stephenson.** It is but a very short time since the steam-engine was invented, and yet what a difference it has made in the habits of the people. Let us consider some of the properties of steam.

Expansion of Steam.—Steam has great power of expansion. You may notice this by watching the water boiling in a kettle. As soon as the water boils, the steam rushes off to find a place to escape; hence it comes out either at the lid or the spout. If the kettle were made air-tight, the force of the steam would burst it.

Elasticity of Steam.—Like all other gases, steam can be compressed, and we can easily prove that it is also elastic. Take an iron cylinder or box fitted with an air-tight piston, and fill it with steam. Now, take care to keep the cylinder and steam at the same heat, and apply a force to the piston so that the steam may be compressed into half the space. If you take away the pressure, the steam will expand to its original size, and will force the piston back to its former position.

This simple experiment illustrates the principle on which the steam-engine is worked. It would be impossible for you to understand the details of its working. The following will, however, give you a general notion: The steam is let into the cylinder from the boiler by two openings, one at each end of the cylinder. First, the steam is let in *below* the piston, so as to drive it *up;* then a slide shuts the opening at the bottom, and opens the one at the top, so that the steam comes in *above* the piston and forces it *down.* Then the slide, which is driven back and forward by the motion of the engine, opens the one below again; and so on, turn about. Meanwhile, the steam, when it has once forced the piston before it, up or down, escapes by an opening in the middle of the cylinder, between the two openings which let it in. The piston is thus kept moving regularly up and down, and being connected with the machinery of the steam-engine, keeps it in motion.

Some other time we shall be able to pursue this matter further. Our object will be accomplished if we have been able in these pages to interest you, so that you may be induced to think for yourselves. Do not be content merely to **see a thing done.** Try in every case to **satisfy yourselves why it is done.** In this way you will gather much useful knowledge, and you will also be able, later in life, to apply that knowledge to some good purpose. He that is observant,

> Finds tongues in trees, books in the running brooks,
> Sermons in stones, and good in everything.

DERIVATION OF DIFFICULT WORDS.

Absorption	Latin *ab*, from, and *sorbeo* (*sorptum*), I suck in.
Accelerated	Lat. *accelerare*, to hasten.
Adhesion	Lat. *ad*, to, and *hæreo* (*hæsum*), I stick.
Alloy	French *à loi*, according to law (a legal mixture).
Amorphous	Greek *a*, without, and *morphē*, form.
Annealing	Anglo-Saxon *anælan*, to inflame, to kindle.
Atmosphere	Gr. *atmos*, vapour, and *sphaira*, a sphere.
Atom	Gr. *a*, not, and *temnō*, I cut.
Barometer	Gr. *baros*, weight, and *metron*, a measure.
Brittle	Anglo-Saxon *breótan*, to break.
Buoyancy	Low Lat. *boia*, a fetter.
Calendar	Lat. *calendæ*, the first day of the Roman month.
Calipers	Short for *Caliber-compasses;* Fr. *calibre*, bore, diameter.
Capillarity	Lat. *capillus*, a hair.
Cohesion	Lat. *con*, together, and *hæreo* (*hæsum*), I stick.
Compasses	Lat. *con*, and *passus*, a step.
Compressibility	Lat. *con*, and *premere*, to press.
Crystalline	Gr. *krustallos*, ice.
Cubical	Gr. *kubos*, a cube.
Divisibility	Lat. *dis*, asunder, and root *vid*, to separate.
Ductility	Lat. *duco*, I lead.
Elasticity	Coined from Gr. *elaō* (*elasō*), to drive.
Equinox	Lat. *æquus*, equal, and *nox*, night.
Evaporation	Lat. *e*, off, and *vapor*, steam.
Expansibility	Lat. *ex*, out, and *pando* (*pansum*), I spread.
Extension	Lat. *ex*, out, and *tendo* (*tensum*), I stretch.
Fibrous	Lat. *fibra*, a thread.
Fluid	Lat. *fluo*, I flow.
Friction	Lat. *frico* (*frictum*), I rub.
Fusibility	Lat. *fundo* (*fusum*), I melt.

Granular	Lat. *granulum*, dim. of *granum*, a grain.
Gravity	Lat. *gravis*, heavy.
Hardness	Anglo-Saxon *heard*, hard.
Imperial	Lat. *imperialis*, from *imperium*, an empire.
Indestructibility	Lat. *in*, not, *de*, down, *struere* (*structum*), to build.
Inertia	Lat. *iners*, *inertis*, unskilful, inactive.
Linear	Lat. *linea*, *linum*, flax = a thread of linen = length without breadth or thickness.
Liquid	Lat. *liquēre*, to melt.
Lunar	Lat. *luna*, the moon.
Malleability	Lat. *malleus*, a hammer.
Measurement	Lat. *mensura*, a measure.
Mechanics	Lat. *mechanicus*, a machine.
Molecule	Fr., a diminutive coined from Lat. *moles*, a mass.
Motion	Lat. *moveo* (*motum*), I move.
Normal	Lat. *normalis*, from *norma*, a rule.
Particles	Lat. *particula*, dim. of *pars*, *partis*, a part.
Pendulum	Lat. *pendeo*, I hang down.
Plastic	Gr. *plassō*, I form or mould.
Pliable	Fr. *plier*, to bend.
Pneumatic	Gr. *pneuma*, wind, air.
Porosity	Gr. *poros*, a small passage.
Retarded	Fr. *retarder*, from Lat. *retardare*, to make slow.
Rigid	Lat. *rigidus*, stiff.
Siphon or Syphon	Gr. *siphōn*, a hollow reed or tube.
Solar	Lat. *sol*, *solis*, the sun.
Specific	Lat. *species*, a particular sort, and *facere*, to make.
Standard	Anglo-Saxon *standan*, to stand.
Structure	Lat. *struo* (*structum*), I build.
Suction	Lat. *sugo* (*suctum*), I suck.
Superficial, Surface	Lat. *super*, above, and *facies*, the face.
Syringe	Gr. *suringx*, a pipe or tube.
Tenacity	Lat. *tenax*, from *teneo*, I hold.
Transmission	Lat. *trans*, across, and *mitto* (*missum*), I send.
Uniform	Lat. *unus*, one, and *forma*, shape.
Unit	Lat. *unus*, one.
Vacuum	Lat. *vacuum*, an empty space.
Vapour	Lat. *vapor*, steam.
Variable	Lat. *varius*, different.
Velocity	Lat. *velox*, *velocis*, swift.
Vitreous	Lat. *vitrum*, glass.

EXAMINATION QUESTIONS.

CHAPTER I.

1. What is meant by matter? How can we detect it? Give ten examples of matter.
2. What is an atom? What is a molecule?
3. What is a solid body? State chief properties of solids.
4. How can you prove the impenetrability of matter?

CHAPTER II.

5. What is meant by cohesion? In what kind of bodies is cohesion strongest?
6. Define hardness. What is the hardest substance known?
7. What do you mean by an alloy? For what purpose are alloys used? Name some alloys.
8. What is gravity? Tell all you know about it.
9. How does a fibrous body differ from a granular body? Give examples of each.
10. What is meant by an amorphous body? Give some examples.

CHAPTER III.

11. How does the transmission of pressure in liquids differ from that in solids?
12. Explain the following: 'Water finds its level,' and show how this knowledge is turned to account.
13. What is meant by the buoyancy of a liquid? Prove that the buoyancy increases with the depth.
14. Explain what is meant by the 'specific gravity' of a body. How would you find the specific gravity of a liquid?
15. Define capillarity, and give an instance of this property.
16. By what means can we convert a liquid into a solid?

CHAPTER IV.

17. State the principal properties of gases. What is the chief difference between a gas and a liquid?
18. How can you prove that the atmosphere possesses weight?
19. What do you know of Otto von Guericke's discoveries?
20. Tell what you know of the Magdeburg hemispheres.

CHAPTER V.

21. Define ductility and malleability. Name some bodies possessing these properties.
22. Define porosity, compressibility, and elasticity.
23. How does a liquid differ from a solid? Name six liquids.
24. Compare the properties of liquids and gases, saying where they agree and where they differ.
25. Explain vapour, fluid, expansion, and permanent gas.

CHAPTER VI.

26. Explain the principle by which water is raised in a pump.
27. What is a siphon? Explain its use.
28. What do you know of Torricelli and Pascal's discoveries?
29. Explain the principle of the air-pump.
30. How is it that you cannot remove the receiver from the plate when a vacuum is caused?
31. What is the use of the barometer? Explain its action.

CHAPTER VII.

32. What do we mean by the 'standard of measurement?' Explain this as fully as you can.
33. What are the standards of linear, superficial, and cubical measures?

CHAPTER VIII.

34. How is time measured? Name instruments used for computing time.
35. What is meant by velocity? Express the velocity of a train which moves a distance of thirty-six miles in three-quarters of an hour.

CHAPTER X.

36. Give a brief description of the manufacture of iron.
37. By what process is iron converted into steel?
38. Tell what you know of the manufacture of glass.
39. Tell what you know of the manufacture of salt.
40. Explain the principle and use of the hydrostatic press.

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