SCIENTIFIC DIALOGUES,

INTENDED FOR THE
INSTRUCTION AND ENTERTAINMENT
OF
YOUNG PEOPLE:
IN WHICH
THE FIRST PRINCIPLES
OF
NATURAL AND EXPERIMENTAL
PHILOSOPHY
ARE FULLY EXPLAINED.

VOL. IV. OF PNEUMATICS.

" Conversation, with the habit of explaining the meaning of words, " and the structure of common domestic implements to children, is the " sure and effectual method of preparing the mind for the acquirement of " science." EDGEWORTH'S PRACTICAL EDUCATION.

BY THE REV. J. JOYCE.

A NEW EDITION, CORRECTED AND IMPROVED.

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CONTENTS

TO

VOL. IV.

APPENDIX.

CONVERSATION I.

OF THE NATURE OF AIR.

FATHER—CHARLES—EMMA.

FATHER. That branch of natural philosophy, which is called Pneumatics, treats of the nature, weight, pressure, and spring of the air which we breathe, and of the several effects dependent upon these properties.

Charles. You told us, a few days ago, that the air, though to us invisible, is a fluid; but it surely differs very much from those fluids which you conversed upon when treating of hydrostatics.

Father. It does so: but recollect the terms by which we defined a fluid.

Charles. You distinguished a fluid as a body, the parts of which yield to the least pressure.

Father. The air, in which we live and move, will answer to this definition. Since we are continually immersed in it, as fish are in the water, if the parts did not yield to the least force, we should be constantly reminded of its presence by the resistance made to our bodies; whereas persons unaccustomed to think on these subjects are not even aware that they are surrounded with a fluid, the weight and pressure of which, if not counterbalanced by some other power, would instantly crush the human frame.

Emma. In a still, calm day, such as the present is, when one can scarcely discern a single leaf in motion, it is difficult to conceive of the existence of such a fluid; but when

> ——————— down at once
> Precipitant, descends a mingled mass
> Of roaring winds, and flames, and rushing
> floods, THOMSON'S SUMMER.

no doubt can remain as to the existence of some mighty unseen power.

Charles. By this quotation, Emma, you take it for granted that the air and the winds are the same.

Father. This is really the fact, as we shall prove on a future day.

Charles. But I am not quite satisfied that the air is such a body as you have described.

Father. I do not wish to proceed a single step till I have made your mind easy upon this head. You see how easily those gold and silver fish move in the water: can you explain the reason of it?

Charles. Is it not by the exertion of their fins?

Father. A fish swims by the help of his fins and tail; and fish in general are nearly of the same specific gravity with water. Take away the water from the vessel, and the fish would have still the use of their fins and tail, at least for a short period.

Emma. And they would flounder about at the bottom.

Father. Now consider the case of birds, how they fly; the swallow, for instance, glides as smoothly along in the air as fish do in the water;

but if I were to put a bird, or even a butterfly, under a glass receiver, however large, and take away the air, they would have no more use of their wings, than fish have of their fins when out of water. You shall see the experiment in a day or two:—

> ———————— If this support
> Were wanting, all the feather'd tribes must drop
> The useless wing. EUDOSIA.

Emma. And would they die in this situation, as fish die when taken from their natural element, the water?

Father. The cases are precisely similar: some fish, as the carp, the eel, and almost all kinds of shell-fish, will live a considerable time out of water; so some creatures, which depend upon air for existence, will live a long time in an exhausted receiver; a butterfly, for instance, will fall to the bottom, apparently lifeless; but admit the air again into the receiver, and it will revive; whereas experiments have been made on mice, rats, birds, rabbits, &c., and it is found, that they will live without air but a very few minutes.

Emma. These are very cruel experiments.

Father. And ought by no means to be indulged in; they can be only justified upon the presumption, that, in the hands and under the direction of able philosophers, they may lead to discoveries of importance to the health and happiness of the human race.

Charles. Can fish live in water from which the air is wholly excluded?

Father. The air is, in fact, as necessary to their existence as it is to ours. Besides their fins, fish have the use of an air-vessel, which gives them full command of their various motions in all depths of water, which their fins without it would not be equal to.

Emma. What do you mean by an air-vessel?

Father. It is a small bladder of air, so disposed within them, that, by the assistance of their muscles, they are able to contract and dilate it at pleasure. By *contraction* they become specifically heavier than the water, and sink; by *dilatation* they are lighter, and rise to the surface more readily.

Charles. Are these operations effected by the external air?

Father. Very much so: for if you take away the air from the water in which a fish is swimming, it will no longer have the power of contracting the air-vessel within, which will then become so expanded as to keep it necessarily on the surface of the water, evidently to its great inconvenience and pain.

If the air-bladder of a fish be pricked or broken, the fish presently sinks to the bottom, unable either to support or raise itself up again. Flat fishes, as soles, plaise, &c., which always lie grovelling at the bottom, have no air-bladder.

CONVERSATION II.

Of the Air-Pump.

EMMA. You have told us, papa of taking away the air from vessels; will you show us how that is performed?

Father. I will; and I believe it will be the most convincing method of proving to you that the air is such a body as I have described.

This instrument (Plate I, Fig. 1) is called an air-pump, and its use is to exhaust or draw away the air from any vessel, as the glass receiver L K.

Charles. Does it act like the common pump?

Father. So much so, that, if you comprehend the nature and structure of the one, you will find but little difficulty in understanding the other. I will, however, describe the different parts. A A are two strong brass barrels, within each of which, at the bottom, is fixed a valve, opening upwards; these valves communicate with a concealed pipe that leads to K. The barrels include also moveable pistons, with valves opening upwards*.

Emma. How are they moved?

Father. To the upper parts of the

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* The reader is supposed to have attended to the structure of the common pump, described Vol. III, of Hydrostatics, Conversation XXI.

pistons is attached rack-work, part of which you see at C C: these racks are moved up and down by means of a little cog-wheel, turned round by the handle R.

Charles. You turn the handle but half way round.

Father. And by so doing, you perceive that one of the racks rises and the other descends.

Emma. What is the use of the screw V?

Father. It serves to re-admit air into the receiver when it is in a state of exhaustion; for without such a contrivance the receiver could never be moved out of its place, after the air was once taken from beneath it: but you shall try for yourselves. I first place a slip of wet leather under the edge of the receiver, because the brass plate is liable to be scratched, and the smallest unevenness between the receiver and plate would prevent the success of our experiment. I have turned the handle but a few times: try to take away the receiver.

Charles. I cannot move it.

Father. I dare say not: for now the greater part of the air is taken from under the receiver, consequently it is pressed down with the weight of the atmosphere on the outside.

Emma. Pray explain how the air was taken away.

Father. By turning the winch R half way round, I raise one of the pistons, and thereby leave a vacuum in the lower part of the barrel, and a portion of the air in the receiver rushes through the pipe into the empty barrel. I then turned the winch the other way, which raised the other piston, and a vacuum would be left in that barrel, did not another portion of air rush from the receiver into it.

Charles. When the first piston descended, did the air in the barrel open the little valve, and escape by the rack c?

Father. It did: and by the alternate working of the pistons, so much of the air is taken away, that the quantity left has not force enough to raise the valve.

Charles. Cannot you take all the air from the receiver?

Father. Not by means of the air-pump.

Emma. What is the reason that a mist comes on the inside of the glass receiver while the air is exhausting?

Father. It is explained by the sudden expansion of the air that is left in the receiver, which we shall notice more particularly in our Conversations on Chemistry. The fact is described, as well as the general operation of the air-pump, by Dr. Darwin:—

—How, as in brazen pumps the pistons move,
The membrane valve sustains the weight
above,
Stroke follows stroke, the gelid vapour falls,
And misty dew-drops dim the crystal walls;
Rare and more rare expands the fluid thin,
And silence dwells with vacancy within.

BOTANICAL GARDEN.

The last line alludes to a fact hereafter to be explained*, namely, that where there is no air there can be no sound.

Charles. You have not told us

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* See Conversation X.

the use of the smaller receiver w, with the bottle of quicksilver within it.

Father. By means of the concealed pipe there is a communication between this and the large receiver, and the whole is intended to show to what degree the air in the large receiver is exhausted. It is called the small barometer-gauge, the meaning of which you will better understand when the structure of the barometer is explained.—I will now show you an experiment or two, by which the resistance of the air is clearly demonstrated.

Emma. Are these mills (Plate I, Fig. 2) for the purpose?

Father. Yes, they are; the machine consists of two sets of vanes, *a* and *b*, made equally, and to move on their axes with the same freedom.

Charles. But the vanes of *a* are placed edgeways, and those of *b* are breadthways.

Father. They are so placed to exhibit in a striking manner the resistance of the atmosphere; for as the little mill *a* turns, it is resisted only in a small degree, and will go round a much longer time than the other, which, in its revolutions, meets the air with its whole surface. By means of the spring *c* resting against the slider *d* in each mill, the vanes are kept fixed.

Emma. Shall I push down the sliders?

Father. Do so: you see that both set off with equal velocities.

Charles. The mill *b* is evidently

declining in swiftness, while the other goes on as quick as ever.

Father. Not quite so; for in a few minutes you will find them both at rest.

Now we will place them under the receiver of the air-pump, and by a little contrivance we shall be able to set the mills a going after the air is exhausted from the receiver; and then, as there is no sensible resistance against them, they will both move round a considerable time longer than they did in the open air, and the instant that one stops the other will stop also.

Emma. This experiment clearly shows the resisting power of the air.

Father. It shows also that its resistance is in proportion to the surface opposed to it: for the vane which met and divided the air by the edge only continued to move the longest, while they were both exposed to it; but when that is removed, they both stop together, because there is nothing now to retard their motion, but the friction on the pivots, which is the same in both cases. Take this guinea and a feather: let them both drop from your hand at the same instant.

Charles. The guinea is soon at rest at my feet, but the feather continues floating about. Is the feather specifically lighter than air?

Father. No: for if it were, it would ascend till it found the air no heavier than itself, whereas, in a minute or two, you will see the feather on the floor as well as the guinea: it is however so light, and presents so large a surface to the air, in comparison to its weight, that it is considerably longer in falling to the ground than heavier bodies, such as a guinea. Take away the resisting medium, and they will both reach the bottom at once.

Emma. How will you do that?

Father. Upon this brass flap (Plate 1, Fig. 3) I place the guinea and the feather, and having turned up the flap, and shut it into a small notch, I fix the whole on a tall receiver, with a piece of wet leather between the receiver and brass. I will now exhaust the air from under the receiver, by placing it over the air-pump, and, if I turn the wire *f* a little, the flap will slip down, and guinea and feather will fall with equal velocities:—

——————In perfect void
All substances with like velocity
Descend, nor the soft down outstrips the gold.
EUDOSIA.

Charles. They are both at the bottom, but I did not see them fall.

Father. While I repeat the experiment, you must look stedfastly to the bottom, because the distance is too small for you to trace their motion; but, by keeping your eye at the bottom, you will see the feather and guinea arrive at the same instant.

In this glass tube (Plate 1, Fig. 4) is some water, but the air is taken away, and the glass completely closed. Turn it up quick, so that the water may fall on the other end.

Emma. It makes a noise like the stroke of a hammer.

Father. And for that reason it is

usually called the philosophical hammer. The noise is occasioned through the want of air to break the fall: for if I take another glass, in all respects like it, but having the air enclosed in it, as well as water, you may turn it as often as you please with hardly any noise.

Charles. Perhaps the air breaks the fall of the water by dividing its particles.

Father. It acts, with respect to water, as water acts with regard to the fall of any other substance thrown into it; it impedes the velocity of the falling body.

CONVERSATION III.

Of the Torricellian Experiment.

CHARLES. If, by means of the air-pump, you cannot perfectly exhaust the air from any vessel, by what means is it done?

Father. This glass tube is about 36 inches long, and open at one end only. I fill it very accurately with quicksilver, and, placing my thumb over the open end, I invert the tube, and plunge it into a vessel of the same metal, taking care not to remove my thumb till the end of the tube is completely immersed in quicksilver. You observe the mercury is suspended in the tube to a certain height, and above it there is a perfect vacuum; that is, in the six or seven inches at the upper part of the tube, the air is perfectly excluded.

Emma. Could not the air get in when you took away your thumb?

Father. You saw that I did not remove my thumb till the open end of the tube was wholly under the quicksilver, therefore no air could get into the tube without first descending through the quicksilver: now you know that a lighter fluid will not descend through one that is heavier, and, consequently, it is impossible than any air should be in the upper part of the tube.

Charles. What makes the quicksilver stand at that particular height?

Father. Before I answer this, tell me the reason why water cannot be raised by means of a common pump higher than about 32 or 33 feet?

Charles. Because the pressure of the atmosphere is equal to the pressure of a column of water so many feet in height*.

Father. And the pressure of a column of quicksilver 29 or 30 inches long, a little more or less according to the variation of the air, is equal to the pressure of a column of water 32 or 33 feet high, and consequently equal to the pressure of the whole height of the atmosphere.

Emma. Is then the mercury in the

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* See Vol. III, Conversation XXI.

tube kept suspended by the weight of the air pressing on that in the cup?

Father. It is.

Emma. If you could take away the air from the cup, would the quicksilver descend in the tube?

Father. If I had a receiver long enough to enclose the cup and tube, and were to place them on the air-pump, you would see the effect that a single turn of the handle would have on the mercury; and, after a very few turns, the quicksilver in the tube would be nearly on a level with that in the cup.

I can show you, by means of this syringe, that the suspension of the quicksilver in the tube is owing to nothing but the pressure of the air.

Charles. What is the structure of the syringe?

Father. If you understand in what manner a common water-squirt acts, you will be at no loss about the syringe, which is made like it.

Charles. By dipping the small end of a squirt in water, and lifting up the handle, a vacuum is made, and then the pressure of the air on the surface of the water forces it into the squirt.

Father. That is the proper explanation.—This vessel D (Plate I, Fig. 5), containing some quicksilver, and the small tube *g f*, 33 inches long, open at both ends, immersed in it, are placed under a large receiver, A B; the brass plate C, put upon it with a piece of wet leather, admits the small tube to pass through it at *h*. I will now screw the syringe H on the tube *g f*, and, by lifting up the handle

I, a partial vacuum is made in the tube, consequently the pressure of the air in the receiver upon the mercury in the cup D forces it up into the little tube as high as x, just in the same manner as water follows the piston in a common pump.

Emma. But is not this rise of the quicksilver in the tube owing to the suction of the syringe?

Father. To prove to you that it is not, I place the whole apparatus over the air pump, and exhaust the air out of the receiver A B. This operation, you must be sensible, has not the smallest effect on the air in the syringe and little tube; but you nevertheless observe, that the mercury has again fallen into the cup D; and the syringe might now be worked for ever without raising the mercury in the tube; but admit the air into the receiver, and its action upon the surface of the quicksilver in the cup will force it instantly into the tube.

This is called the Torricellian experiment, in honour of Torricelli, a learned Italian, and disciple of Galileo, who invented it, and who was the first person that discovered the pressure and weight of the air.

Charles. Was not the true nature of the atmosphere understood before the time of Torricelli?

Father. No: he was the father of all the modern discoveries respecting the properties of the atmospheric air. He died at the age of 40, when great hopes were formed of his talents and genius.

CONVERSATION XIV.

Of the Pressure of the Air.

CHARLES. It seems very surprising that the air, which is invisible, should produce such effects as you have described.

Father. If you are not satisfied with the evidence which your eyes are capable of affording, you would perhaps have no objection to the information which your feelings may convey to your mind. Place this little glass A B, open at both ends (Plate I, Fig. 6), over the hole of the pump plate, and lay your hand close upon the top B, while I turn the handle of the pump a few times.

Charles. It hurts me very much: I cannot take my hand away.

Father. By letting in the air, I have released you. The pain was occasioned by the pressure of the air on the outside of your hand, that being taken away from under it, which served to counterbalance its weight.

This is a larger glass of the same kind (Plate 1, Fig. 7); over the large end, I tie a piece of wet bladder very tight, and will place it on the pump, and take the air from under it.

Emma. Is it the weight of air that bends the bladder so much?

Father. Certainly: and if I turn the handle a few more times it will burst.

Charles. It has made a report as loud as a gun.

Father. A piece of thin flat glass may be broken in the same manner. Here is a glass bubble A, with a long neck (Plate I, Fig. 8), which I put into a cup of water B, and place them under a receiver on the plate of the air pump, and, by turning the handle, the air is not only taken from the receiver, but that in the hollow glass ball will make its way through the water and escape.

Emma. Is it the air which occasions the bubbles at the surface of the water?

Father. It is. Now the bubbling is stopped, and therefore I know that as much of the air is taken away as can be got out by means of the pump. The hollow ball is still empty: but by turning the cock v of the pump (Fig. 1) the air rushes into the receiver and presses upon the water, thereby filling the ball with the fluid.

Charles. It is not quite full.

Father. That is because the air could not be perfectly exhausted, and the little bubble of air at the top is what, in its expanded state, filled the whole glass ball, and now, by the pressure of the external air, it is reduced into the size you see it.

Another very simple experiment will convince you that suction has nothing to do with these experiments. On the leather of the air-pump, at a little distance from the hole, I place lightly this small receiver *x*, and pour a spoonful or two of water round the edge of it (Plate I,

Fig. 9). I now cover it with a larger receiver A B, and exhaust the air.

Emma. I see by the bubbles round the edge of the small receiver that the air is making its way from under it.

Father. I have pretty well exhausted all the air; can you move the large receiver?

Charles. No: but by shaking the pump, I see the little one is loose.

Father. The large one is rendered immovable by the pressure of the external air. But the air being taken from the inside of both glasses, there is nothing to fasten down the smaller receiver.

Emma. But, if suction had any thing to do with this business, the little receiver would be fast, as well as the other.

Father. Turn the cock v of the air-pump quickly. You hear the air rushing in with violence.

Charles. And the large receiver is loosened again.

Father. Take away the smaller one, Emma.

Emma. I cannot move it with all my strength.

Father. Nor could you lift it up if you were a hundred times stronger than you are. For by admitting the air very speedily into the large receiver, it pressed down the little one before any air could get underneath it.

Charles. Besides, I imagine you put the water round the edge of the glass to prevent the air from rushing between it and the leather.

Father. You are right; for air,

being the lighter fluid, could not descend through the layer of water in order to ascend into the receiver.—Could suction produce the effect in this experiment?

Charles. I think not; because the little receiver was not fixed till after what might be thought suction had ceased to act.

Father. Right: and to impress this fact strongly on your mind, I will repeat the experiment. You observe that the air being taken from under both receivers, the large one must be fixed by the pressure of the atmosphere, and the smaller one is loose, because there is no pressure on its outside to fasten it. But by admitting the air, the inner one becomes fixed by the very means that the outer one is loosened.

Emma. How will you get the small one away?

Father. As I cannot *raise* it, I must slide it over the hole in the brass plate; and now the air gets under it, there is not the smallest difficulty.

Charles. Would it be possible to raise the small glass?

Father. If the experiment be well executed, it could scarcely be lifted up by the strength of any person. But by introducing the air under it, all difficulty vanishes.

CONVERSATION V.

Of the Pressure of the Air.

CHARLES. Although suction has nothing to do in the experiments which you made yesterday, yet I think I can show you an instance in which it has. This experiment, if such it may be called, I have made a hundred times. I fasten a string in the centre of a round piece of leather, and, having thoroughly soaked it in water, I press it on a flat stone, and by pulling at the string the leather draws up the stone, although it be not more than two or three inches in diameter, and the stone weighs several pounds. Surely this is suction.

Father. I should say so too, if I could not account for it by the pressure of the atmosphere. By pressing the wet leather on the stone you displace the air, then by pulling the string a vacuum is left at the centre, and the pressure of the air about the edges of the leather is so great, that it requires a greater power than the gravity of the stone to separate them. I have seen you drink water from a spring by means of a hollow straw.

Emma. Yes, that is another instance of what we have been accustomed to call suction.

Father. But now you know, that in this operation you make a syringe with the straw and your lips, and by drawing in your breath you cause a vacuum in the hollow straw tube, and the pressure of the air on the water in the spring forces it up through the straw into the mouth.

Charles. I cannot, however, help thinking that this looks like suction, for the moment I cease the drawing in my breath, the water ceases to rise in my mouth.

Father. That is when there is no longer a vacuum in the straw, the pressure within is just equal to that without, and consequently the water will rest at its natural level.

I will show you another striking instance of the effects of the air's pressure. This instrument (Plate 1, Fig. 10) is called the transferrer. The screw c fits on to the plate of the air-pump, and by means of the stop-cocks G and H I can take away the air from both, or either of the receivers, I K, at pleasure.

Emma. Is there a channel then running from C through D A B, and thence passing to *z* and *y?*

Father. There is. I will screw the whole on the air-pump, and turn the cock G, so that there is now no communication from C to the internal part of the receiver I. At present you observe that both the receivers are perfectly free. By turning the handle of the pump a few times the air is taken away from the receiver K, and, to prevent its re-entrance, I turn the stop-cock *d.* Try if you can move it.

Charles. I cannot: but the other is loose.

Father. The pressure of the atmosphere is evidently the same on the two receivers; but with regard to the glass I, the pressure within is equal to that without, and the glass is free: in the other, the pressure from within is taken away, and the glass is fixed. In this state of the experiment you are satisfied that there is a vacuum in the receiver K. By turning the cock G, I open a communication between the two receivers, and you hear the air that was in I rush through the channel A B into K. Now try to move the glasses.

Emma. They are both fixed: how is this?

Father. The air that was enclosed in the glass I is equally diffused between the two, consequently the internal pressure of neither is equal to the external, and therefore they are both fixed by the excess of the external pressure over the internal. In this case it could not be suction that fixed the glass I, for it was free long after what might have been thought suction had ceased to act.

Charles. What are these brass cups? (Plate I, Fig. 11.)

Father. They are called the hemispherical cups; I will bring the two, B A, together, with a wet leather between them, and then screw them by D to the plate of the air-pump: and, having exhausted the air from the inside, I turn the stop-cock E, take them from the pump, and screw on the handle F. See if you two can separate them.

Emma. We cannot stir them.

Father. If the diameter of these cups were four inches, the pressure to be overcome would be equal to 180lbs. I will now hang them up in the receiver (Plate I, Fig. 12) and exhaust the air out of it, and you see they separate without the application of any force.

Charles. Now there is no pressure on the outside, and therefore the lower cup falls off by its own gravity.

Father. With this steel-yard (Plate II, Fig. 13) you may try very accurately to what weight the pressure of the atmosphere against the cups is equal *.

Emma. For when the weight w is carried far enough to overcome the pressure of the cups, it lifts up the top one.

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* The principle of the steel-yard is explained, Vol. I, of Mechanics, Conver. XV.

Father. I have exhausted the air of this receiver H (Plate II, Fig. 14), consequently it is fixed down to the brass plate I; to the plate is joined a small tube with a stop-cock *x*; by placing the lower end of the tube in a bason of water, and turning the cock, the pressure of the atmosphere on the water in the bason forces it through the tube in the form of a fountain. This is called the fountain *in vacuo.*

To this little square bottle A (Plate II, Fig. 15) is cemented a screw valve, by which I can fix it on the plate of the air-pump, and exhaust its air; and you will see, that when there is no power within to support the pressure of the atmosphere from without it will be broken into a thousand pieces.

Charles. Why did you not use a round phial?

Father. Because one of that shape would have sustained the pressure like an arch.

Emma. Is that the reason why the glass receivers are able to bear such a weight without breaking?

Father. It is. If mercury be poured into a wooden cup c, made of willow, which is a very porous kind of wood (Plate II, Fig. 16), and the air taken from under it, the mercury will, by the weight of the external air, be forced through the pores of the wood, and descend like a shower of rain.

CONVERSATION VI.

Of the Weight of Air.

EMMA. We have seen the surprising effects of the air's pressure; are there any means of obtaining the exact weight of air?

Father. If you do not require any very great nicety, the method is very simple.

This Florence flask (Plate II, Fig. 17) is fitted up with a screw, and a fine oiled silk valve at D. I will now screw the flask on the plate of the air-pump, and exhaust the air. You see, in its present exhausted state, it weighs 3 ounces and 5 grains.

Charles. Cannot the air get through the silk ?

Father. The silk, being varnished with a kind of oily substance, is impenetrable to air; and, being exhausted, the pressure upon the outside effectually prevents the entrance of the air by the edges of the silk; but if I lift it up by means of this sewing-needle, you will hear the air rush in.

Emma. Is that hissing noise occasioned by the re-entrance of the air?

Father. It is; and when that ceases, you may be sure the air within the bottle is of the same density as that without.

Charles. If I weigh it again, the difference between the weight now, and when you tried it before, is the weight of the quantity of air contained in the bottle: it weighs very accurately 3 ounces 19¼ grains, consequently the air weighs 14¼ grains.

Father. And the flask holds a quart, wine-measure.

Emma. Does a quart of air always weigh 14¼ grains?

Father. The weight of the air is perpetually changing; therefore, though a quart of it weighs to-day 14¼ grains, the same quantity may, in a few hours, weigh 14½ grains, or perhaps only 14 grains, or more or less. The air is much heavier this morning than it was at the same time yesterday.

Charles. How do you know that; did you weigh some yesterday?

Father. No: but the rising and falling of the quicksilver in the barometer, an instrument which I shall hereafter very particularly describe, are sure guides by which the real weight of the air is estimated: and it stands full three-tenths of an inch higher now than it did yesterday.

Emma. Will you explain how we may judge of the different weights of the air by the barometer?

Father. This subject might, perhaps, be better discussed when we come to treat explicitly on that instrument; but I will now answer your inquiry, although I should be in some danger of a repetition on a future day.

The mercury in a well-made barometer will always subside till the weight of the column be exactly equivalent to the weight of the external air upon the surface of the mercury in the bason, consequently the height of the mercury is a sure criterion by which that weight is to be estimated.—Suppose, for example, the barometer stands at 29½ inches, or, as it is usually expressed, at 29.5, and I find a quart of air at that time weighs 14½ grains. Here then is a standard by which I may ever after compare the gravity of the atmosphere. If to-morrow I find the quicksilver has fallen to 29.3, I shall know the air is not so heavy as it was; because, in this case, a column of quicksilver 29.3 inches balances the whole weight; whereas it required, before, a column equal to 29.5. If, on the contrary, when I look again, the mercury has risen to 30.6, as it really stands at this hour, Sept. 29, 1805, I am sure the atmosphere is considerably heavier than it was before, and that a quart of it will weigh much more than 14½ grains.

Charles. You intimated, that in weighing the air the flask could not be depended upon, if great nicety were required: what is the reason of that?

Father. I told you, when explaining the operations of the air-pump, that it was impossible to obtain, by means of that instrument, a perfect vacuum. The want of accuracy in the flask experiment depends on the small quantity of air that is left in the vessel after the exhaustion is carried as far as it will go: this, however, if the pump be good, will, after 12 turns of the handle, be less than the 4000th part of the whole quantity.

Emma. How do you know this?

Father. You seem unwilling to take any thing upon my word; and in subjects of this kind you do right, never to rest satisfied without a reason for what is asserted.

I suppose, then, each of the barrels of the air-pump is equal in capacity to the flask; that is, each will contain a quart; then it is evident, that, by turning the handle of the pump, I exhaust all the air of one barrel, and the air in the flask becomes at the same time equally diffused between the barrel and flask; that is, the quart is now divided into two equal parts, one of which is in the flask and the other in the barrel. By the same reason, at the next turn of the handle, the pint in the flask will be reduced to half a pint; and so it will go on decreasing, by taking away, at every turn, one half of the quantity that was left in by the last turn.

Charles. Do you mean then, that after the first turn of the handle, the air in the bottle is twice as rare as it was at first; and after the second, third, and fourth turns, it is four times, eight times, and sixteen times as rare as it was when you began?

Father. That is what I meant; carry on your multiplication, and you will find that after the twelfth turn it is 4096 times more rare than it was at first.

Emma. I now understand that, though absolute exactness be not attainable, yet, in weighing this quart of air, the error is only equal to the 4096th part of the whole, which quantity may, in reasoning on the subject, be overlooked.

Father. I will exhaust the flask again of its air, and, putting the neck of it under water, I will lift up the silk valve and fill it with water. Now dry the outside very thoroughly and weigh it.

Charles. It weighs 27 ounces.

Father. Subtract the weight of the flask, and reduce the remainder into grains, and divide by $14\frac{1}{4}$, and you will obtain the specific gravity of water compared with that of air.

Charles. I have done it, and the water is something more than 800 times heavier than air.

Father. Since, then, the specific gravity of water is always put at 1, that of air must be as $\frac{1}{800}$th, at least according to this calculation; but following the more accurate experiments of Mr. Cavendish and others, whose authority may be safely appealed to, the specific gravity of air is 800 times less than that of water, when the barometer stands as high as 30 inches.

Can you tell me what the air in this room weighs? The length of the room is 25 feet, the height 10½, and the width 12½?

Emma. I multiply these three numbers together, and the answer is 3281.25; or the room contains a little more than 3281 cubic feet: now a cubic foot of water weighs 1000 ounces, therefore the weight of the room full of water would be 3,281,000 ounces; but air being 800 times lighter than water, the air in the room will weigh 3,281,000 ÷ 800 = 4101 ounces = 256 lbs. 5 oz. It seems, however, surprising that the air, which is invisible, should weigh so much.

CONVERSATION VII.

Of the Elasticity of Air.

FATHER. I have told you that air is an elastic fluid. Now it is the nature of all elastic bodies to yield to pressure, and to endeavour to regain their former figure as soon as the pressure is taken off. In projecting an arrow from your bow, you exert your strength to bring the two ends of the bow near together, but the moment you let go the string, it recovers its former shape: the power by which this is effected is called *elasticity*.

Emma. Is it not by this power that India-rubber, after it has been stretched, recovers its usual size and form?

Father. It is: and almost every thing that you make use of possesses this property in a greater or less degree: balls, marbles, the chords of musical instruments, are all elastic.

Charles. I understand how all these things are elastic: but do not see in what manner you can prove the elasticity of the air*.

Father. Here is a bladder, which we will fill with air, and tie up its mouth to prevent it escaping again. If you now press upon it with your hand, its figure will be changed; but the moment the pressure is removed it recovers its round shape.

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* See Vol. I, of Mechanics, Conver. XIII.

Emma. And if I throw it on the ground, or against any other obstacle, it rebounds like a ball or marble.

Father. You are satisfied also, I presume, that it is the air which is the cause of it, and not the bladder that contains it.

Let us now have recourse to the air-pump to exhibit some of the more striking effects of the air's elasticity. I will let a part of the air out of the bladder, and tie up its mouth again. The pressure of the external air renders it flaccid, and you may make what impression you please upon it, without its endeavouring to re-assume its former figure.

Emma. What proof is there that this is owing to the external pressure of the air?

Father. Such as will satisfy you

both, I am sure. Place it under the receiver of the air-pump, exhaust the air, and see the consequences.

Charles. It begins to swell out; and now it is as large as when it was blown out full of air.

Father. The outward pressure being in part removed, the particles of air, by their elasticity, distend, and fill up the bladder; and if it were much larger, and the exhaustion were carried farther, the same small quantity of air would fill it completely. I will now let the air in again.

Emma. This exhibits a very striking proof of the power and pressure of the external air, for the bladder is as flaccid as it was before.

Father. I put the same bladder into this square box without any alteration, and place upon it a moveable lid, upon which I put this weight. By bringing the whole under a receiver, and exhausting the external air, the elasticity of that in the bladder will lift up the lid and weight together.

Charles. If you pump much more, the weight will fall against the side of the glass.

Father. I do not mean to risk that:—it is enough that you see a few grains, not half a dozen, of air will, by their elasticity, raise and sustain a weight of several pounds.

Take this glass bubble (Plate 1, Fig. 8): the bore of the tube is too small for the water to run out; but if I place it under the receiver of the air-pump, and take away the external air, the little quantity of air which is at the top of the glass, will, by its elastic force, expand itself, and drive out all the water.

Emma. This experiment shows, that a very small quantity of air is capable of filling a large space, provided the external pressure is taken off.

Father. Certainly: I will take off the bladder from this glass. (See Plate III, Fig. 18, Vol. III.) The little images all swim at the top, the air contained in them rendering them rather lighter than the water. Tie little leaden weights to their feet, these pull them down to the bottom of the vessel. I now place the glass under the receiver of the air-pump, and, by exhausting the air from the vessel, that which is within the images, by its elasticity, expands itself, forces out more water, and you see they are ascending to the top dragging the weights after them. I will let in the air, and the pressure forces the water into the images again, and they descend.

Here is an apple very much shrivelled, which, when placed under the receiver, and the external air taken away, will appear as plump as if it were newly gathered from the tree.

Emma. Indeed it now looks so inviting, that I am ready to wish it was my own.

Father. Before, however, you can get it, all its beauty will fade. I will admit the air again.

Charles. It is as shrivelled as ever. Do apples contain air?

Father. Yes, a great deal; and so, in fact, do almost all bodies that are specifically lighter than water, as well as many that are not so. It was the elastic power of the air within the apple, that forced out all the shrivelled parts when the external pressure was taken away.

Here is a small glass of warm ale, from which I am going to take away the air.

Emma. It seems to boil, now you exhaust the air from the receiver.

Father. The bubbling is caused by the air endeavouring to escape from the liquor. Let the air in again, and then taste the beer.

Charles. It is flat and dead.

Father. You see of what importance air is to give to all our liquors their pleasant and brisk flavour, for the same will happen to wine and all other fermented fluids.

Emma. How is it that the air, when it was re-admitted, did not penetrate the ale again?

Father. It could not insinuate itself into the pores of the beer, because it is the lighter body, and therefore will not descend through the heavier. Besides, it does not follow that it is the same sort of air which I admitted into the receiver, that was taken from the ale.

Emma. Are there more kinds of air than one?

Father. Yes, very many; as we shall show you in our Conversations on Chemistry *. That which I took from the beer, and which gives it the brisk and lively taste, is called fixed air, or carbonic acid gas, of which there is, in general, but a

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* See Dialogues in Chemistry, Vol. I.

very small quantity in the atmosphere.

The elasticity, or spring of air, contained in our flesh, was clearly shown by the experiment, when I pumped the air from under your hand.

Charles. Was that the cause of its swelling downward?

Father. It was: and it will account for the pain you felt, which was greater, and of a very different kind, than what you would have experienced by a dead weight being laid on the back of your hand, equal to the pressure of the air.

Cupping is an operation performed on this principle: the operator tells you he draws up the flesh; but if he were to speak correctly, he would say, he took away the external air from off a certain part of the body, and then the elastic force of the air within extends, and swells out the flesh ready for his lancets.

Emma. When I saw you cupped he did not use an air-pump, but little glasses, to raise the flesh.

Father. Glasses closed at top are now generally made use of, in which the operator holds the flame of a lamp: by the heat of this the elasticity of the air in the glass is increased, and thereby a great part of it driven out. In this state the glass is put on the part to be cupped, and as the inward air cools, it contracts, and the glass adheres to the flesh by the difference of the pressures of the internal and external air.

By some persons, however, the syringe is considered as the most effectual method of performing the operation, because by flame the air cannot be rarified more than one half, whereas by the syringe a few strokes will nearly exhaust it.

Here is another little square bottle like that before mentioned (Plate II, Fig. 15), only that it is full of air, and the mouth sealed so closely that none of it can escape. I enclose it within the wire cage B, and in this state bring them under the receiver, and exhaust the external air.

Charles. With what a loud report it has burst!

Father. You can easily conceive now in what manner this invisible fluid endeavours continually, by its elastic force, to dilate itself.

Emma. Why did you place the wire cage over the bottle?

Father. To prevent the pieces of

the bottle from breaking the receiver, an accident that would be liable to happen without this precaution.

Take a new-laid egg, and make a small hole in the little end of it, then, with that end downwards, place it in an ale-glass under the receiver, and exhaust the air; the whole contents of the egg will be forced out into the glass, by the elastic spring of the small bubble of air which is always to be found in the large end of a new-laid egg.

CONVERSATION VIII.

Of the Compression of the Air.

FATHER. I have already alluded to the compressibility of air, which it is proper to describe here, it being a consequence of its elasticity: for whatever is elastic is capable of being forced into a smaller space. In this respect air differs very materially from other fluids.

Charles. You told us that water was compressible in a very small degree.

Father. I did so; but the compression, which can be effected with the greatest power, is so very small, that, without the greatest attention and nicety in conducting the experiments, it would never have been discovered. Air, however, is capable of being compressed into a very small space compared with what it naturally possesses.

Emma. The experiment you made, by plunging an ale-glass with its mouth downwards, clearly proved that the air which it contained was capable of being reduced into a smaller space.

Father. This bended tube A B C (Plate II, Fig. 18) is closed at A and open at C. It is in the common state, full of air. I first pour into it a little quicksilver, just sufficient to cover the bottom *a b*: now the air in each leg is of the same density, and, as that contained in A B cannot escape, because the lighter fluid will be always uppermost, when I pour more quicksilver in at C, its weight will condense the air in the leg A B; for the air, which filled the whole length of the leg, is, by the weight of the quicksilver in C B, pressed into the smaller space A *x*, which space will be diminished as the weight is increased: so that, by increasing the length of the column of mercury in C B, the air in the other leg will be more and more condensed. Hence we learn that the elastic spring of air is always, and under all circumstances, equal to the force which compresses it.

Charles. How is that proved?

Father. If the spring, with which the air endeavours to expand itself when it is compressed, were less than the compressing force, it must yield still farther to that force; that is, if the spring of the air in A x were less than equal to the weight of the mercury in the other leg, it would be forced into a yet smaller space; but if the spring were greater than the weight pressing upon it, it would not have yielded so much; for you are well aware that action and re-action are equal, and act in opposite directions.

You can now easily understand why the lower regions of the atmosphere are more dense than those higher.

Emma. Because they are pressed upon by all the air that is above them, and therefore condensed into a smaller space.

Father. Consequently the air grows gradually thinner, till at a considerable height it may be conceived to degenerate to nothing. The different densities of the air may be illustrated by conceiving twenty or thirty equal packs of wool placed one upon another; the lowest will be forced into a less space, that is, its parts will be brought nearer together and it will be more dense than the next; and that will be more dense than the third from the bottom, and so on till you come to the uppermost, which sustains no other pressure than that occasioned by the weight of the incumbent air.

Let us now see the effects of condensed air, by means of an artificial fountain. This vessel is made of strong copper (Plate II, Fig. 19), and is about half full of water. With a syringe that screws to the pipe B A I force a considerable quantity of air into the vessel, so that it is very much condensed. By turning the stop-cock B, while I take off the syringe, no water can escape: and, instead of the syringe, I put on a jet, or very small tube, after which the stop-cock is turned, and the pressure of the condensed air forces the water through the tube to a very great height.

Charles. Do you know how high it ascends?

Father. Not exactly: but as the natural pressure of the air will raise water 33 feet, so if by condensation its pressure be tripled, it will rise 66 feet.

Emma. Why tripled? Ought it

not to rise to this height by a double pressure?

Father. You forget that there is the common pressure always acting against, and preventing the ascent of the water; therefore, besides a force within to balance that without, there must be a double pressure.

Charles. You described a syringe to be like a common water squirt—how are you able, by an instrument of this kind, to force in so great a quantity of air? Will it not return by the same way it is forced in?

Father. The only difference between a condensing syringe and a squirt is, that, in the former, there is a valve that opens downwards, by which air may be forced through it; but the instant that the downward pressure ceases, the valve, by means of a strong spring, shuts of itself, so that none can return.

Emma. Will not air escape back during the time you are forcing in more of the external air?

Father. That would be the case if the syringe pipe went no lower than that part of the vessel which contains the air; but it reaches to a considerable depth in the water; and, as it cannot find its way back up the pipe, it must ascend through the water, and cause that pressure upon it which has been described.

Charles. To what extent can air be compressed?

Father. If the apparatus be strong enough, and a sufficient power applied, it may be condensed several thousand times; that is, a vessel, which will contain a gallon of air in its natural state, may be made to contain several thousand gallons.

By means of a fountain of this kind, young people, like yourselves, may receive much entertainment with only a few additional jets, which are made to screw on and off. One kind is so formed that it will throw up and sustain on the stream a little cork ball, scattering the water all round. Another is made in the form of a globe, pierced with a great number of holes, all tending to the centre, exhibiting a very pleasing sphere of water. One is contrived to show, in a neat manner, the composition and resolution of forces explained in our first volume*. Some will form cascades; and by others you may, when the sun shines at a

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* See Vol. I, of Mechanics, Conver. XIII.

certain height in the heavens, exhibit artificial rainbows*.

We will now force in a fresh supply of air, and try some of these jets.

Emma. I observed in the upright jets, that the height to which the water was thrown was continually diminishing.

Father. The reason is this; that, in proportion as the quantity of water in the fountain is lessened, the air has more room to expand, the compression is diminished, and consequently the pressure becomes less, till at length it is no greater within than it is without, and then the fountain ceases altogether.

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* This phenomenon is described and explained in Vol. V, Conversation XVIII.

CONVERSATION IX.

Miscellaneous Experiments on the Air-Pump.

FATHER. I shall, to-day, exhibit a few experiments, without any regard to the particular subjects under which they might be arranged.

In this jar of water I plunge some pieces of iron, zinc, stone, &c., and you will see that when I exhaust the external air, by bringing the jar under the receiver of the air pump, the elastic spring of air contained in the pores of these solid substances will force them out in a multitude of globules, and exhibit a very pleasing spectacle, like the pearly dew-drops on the blades of grass; but when I admit the air, they suddenly disappear.

Emma. This proves what you told us a day or two ago, that substances in general contain a great deal of air.

Father. Instead of bodies of this kind, I will plunge in some vegetable substances, a piece or two of the stem of beet-root, angelica, &c., and now observe, when I have exhausted the receiver, what a quantity of air is forced out of the little vessels of these plants by means of its elasticity.

Charles. From this experiment we may conclude, that air makes no small part of all vegetable substances.

Father. To this piece of cork, which of itself would swim on the surface of water, I have tied some lead, just enough to make it sink. But, by taking off the external pressure, the cork will bring the lead up to the surface.

Emma. Is that because, when the pressure is taken off, the substance of the cork expands, and becomes specifically lighter than it was before?

Father. It is: this experiment is varied by using a bladder, in which is tied up a very small quantity of air, and sunk in water: for when the external pressure is removed, the spring of air within the bladder will expand it, make it specifically lighter than water, and bring it to the surface.

The next experiment shows, that the ascent of smoke and vapours depends on the air. I will blow out this candle, and put it under the receiver: the smoke now rises to the top, but as soon as the air is exhausted to a certain degree, the smoke descends, like all other heavy bodies.

Charles. Do smoke and vapours rise because they are lighter than the surrounding air?

Father. That is the reason: sometimes you see smoke from a chimney rise very perpendicularly in a long column; the air then is very heavy: at other times you may see it descend, which is a proof that the density of the atmosphere is very much diminished, and is, in fact, less than that of the smoke. And at all times the smoke can ascend no higher than where it meets with air of a density equal to itself, and there it will spread about like a cloud.

This figure (Plate II, Fig. 20) is usually called the lungs-glass: a bladder is tied close about the little pipe *a*, which is screwed into the bottle A. I introduce it under the receiver A B, and begin to exhaust the air of the receiver, and that in the bladder communicating with it, will also be withdrawn; the elastic force of the air in the bottle A will now press the bladder to the shrivelled state represented in the figure: I will admit the air which expands the bladder; and thus, by alternately exhausting and re-admitting the air, I show the action of the lungs in breathing. But perhaps the following experiment will give a better idea of the subject (Plate II, Figs. 21 and 22). A represents the lungs, B the windpipe leading to them, which is closely fixed in the neck of the bottle, from which the air cannot escape: D is a bladder tied to the bottom, and in its distended state (Fig. 21) will, with the internal cavity of the bottle, represent the cavity of the body which surrounds the lungs, at the moment you have taken in breath: I force up D (as in Fig. 22), and now the bladder is shrivelled by the pressure of the external air in the bottle, and represents the lungs just at the moment of expiration.

Emma. Does Fig. 21 show the state of the lungs after I have drawn in my breath, and Fig. 22 when I have thrown it out forcibly?

Father. That is what the figures are intended to represent, and they are well adapted to show the elevation and compression of the lungs; although I do not mean to assert, that the action of the lungs in breathing depends upon air in the same manner as that in the bladder does upon the air which is contained in the cavity of the bottle.

I have exactly balanced on this scale beam a piece of lead and a piece of cork: in this state I will introduce them under the receiver, and exhaust the air.

Charles. The cork now seems to be heavier than the lead.

Father. In air each body *lost* a weight proportional to its *bulk*, but when the air is taken away, the weight lost will be restored; but the lead lost least, it will now regain the least, consequently the cork will preponderate with the difference of the weights restored by taking away the air.

Thus you see, that, *in vacuo, a pound of cork, or feathers,* would be heavier *than a pound of lead.*

Emma. Why do bodies, when weighed in air, lose weights proportional to their bulks?

Father. Because the air, being a fluid substance, tends to lift up a body immersed in it, and the larger the body, the more effect it will have upon it: of course, it has more effect on an ounce of cork, than on an ounce of lead.

CONVERSATION X.

Of the Air-gun, and Sound.

FATHER. The air-gun is an instrument, the effects of which depend on the elasticity and compression of air.

Emma. Is it used for the same purposes as common guns?

Father. Air-guns will answer all the purposes of a musket or fowling-piece: bullets discharged from them will kill animals at the distance of 50 or 60 yards. They make no report, and on account of the great mischief they are capable of doing, without much chance of discovery, they are deemed illegal, and are, or ought to be, found nowhere but among the apparatus of the experimental philosopher.

Charles. Can you show us the construction of an air-gun?

Father. It was formerly a very complex machine, but now the construction of air-guns is very simple; this (Plate II, Fig. 23) is one of the most approved.

Emma. In appearance it is very much like a common musket, with the addition of a round ball c.

Father. That ball is hollow, and contains the condensed air, into which it is forced by means of a syringe, and then screwed to the barrel of the gun.

Charles. Is there fixed to the ball a valve opening inwards?

Father. There is: and when the leaden bullet is rammed down, the trigger is pulled back, which forces down the hook *b* upon the pin connected with the valve, and liberates a portion of the condensed air; this, rushing through a hole in the lock into the barrel, will impel the bullet to a great distance.

Emma. Does not all the air escape at once?

Father. No: if the gun be well made, the copper ball will contain enough for 15 or 20 separate charges: so that one of these is capable of doing much more execution in a given time than a common fowling-piece.

Charles. Does not the strength of the charges diminish each time?

Father. Certainly; because the condensation becomes less upon the loss of every portion of air; so that after a few discharges the bullet will be projected only a short distance. To remedy this inconvenience, you might carry a spare ball or two ready filled with condensed air in your pocket, to screw on when the other was nearly exhausted. Formerly, this kind of instrument was attached to gentlemen's walking sticks.

Charles. I should like to have one of them.

Father. I dare say you would: but you must not be trusted with instruments capable of doing much mischief, till it is quite certain that your reason will restrain you from actions that might annoy other persons.

A still more formidable instrument is called the *Magazine Wind-gun.* In this there is a magazine of bullets as well as another of air, and when it is properly charged, the bullets may be projected one after another as fast as the gun can be cocked, and the pan opened. The syringe in these is fixed to the but of the gun, by which it is easily charged, and may be kept in that state for a great while.

Emma. Does air never lose its elastic power?

Father. It would be too much to assert that it never will: but experiments have been tried upon different portions of it, which have been found as elastic as ever after the lapse of many months, and even years.

Charles. What is this bell for?

Father. I took it out to show you,

that air is the medium by which, in general, sound is communicated. I will place it under the receiver of the air-pump, and exhaust the air. Now observe the clapper of the bell while I shake the apparatus.

Emma. I see clearly that the clapper strikes the side of the bell, but I do not hear the least noise.

Father. Turn the cock and admit the air: now you hear the sound plain enough: and if I use the syringe and a different kind of glass, so as to condense the air, the sound will be very much increased. Dr. Desaguliers says, that, in air that is twice as dense as common air, he could hear the sound of a bell at double the distance.

Charles. Is it on account of the different densities of the atmosphere, that we hear St. Paul's clock so much plainer at one time than another?

Father. Undoubtedly the different degrees of density in the atmosphere will occasion some difference, but the principal cause depends on the quarter from which the wind blows, for as the direction of that is towards or opposite to our house, we hear the clock better or worse.

Emma. Does it not require great strength to condense air?

Father. That depends much on the size of the piston belonging to the syringe; for the force required increases in proportion to the square of the diameter of the piston.

Suppose the area of the base of the piston is one inch, and you have already forced so much air into the vessel that its density is double that of common air, the resistance opposed to you will be equal to 15 pounds; but if you would have it 10 times as dense, the resistance will be equal to 150 pounds.

Charles. That would be more than I could manage.

Father. Well, then, you must take a syringe, the area of whose piston is only half an inch; and in that case the resistance would be equal to only the fourth part of 150 pounds, because the square of $\frac{1}{2}$ is equal to $\frac{1}{4}$*.

Emma. You said that the air was *generally* the medium by which sound is conveyed to our ears; is it not always so?

Father. Air is always a good conductor of sound, but water is a still

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* The square of any number being the number multiplied into itself, $\frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$.

better. Two stones being struck together under water, the sound may be heard at a greater distance by an ear placed under water in the same river, than it can through the air. In calm weather, a whisper may be heard across the Thames.

The slightest scratch of a pin, at one end of a long piece of timber may be heard by an ear applied near the other end, though it could not be heard at half the distance through the air.

The earth is not a bad conductor of sound: it is said, that, by applying the ear to the ground, the trampling of horses may be heard much sooner than it could through the medium of the air. Recourse has sometimes been had to this mode of learning the approach of a hostile army.

Take a long strip of flannel, and in the middle tie a common poker, which answers as well as any thing, leaving the ends at liberty; these ends must be rolled round the end of the first finger of each hand, and then stopping the ears with the ends of these fingers, strike the poker, thus suspended, against any body, as the edge of a steel fender; the depth of the tone which the stroke will return is amazing; that made by the largest church bell is not to be compared with it. Thus it appears that flannel is an excellent conductor of sound.

CONVERSATION XI.

Of Sound.

FATHER. We shall devote this Conversation to the consideration of some curious circumstances relating to sound; which, as depending upon the air, will come very properly under Pneumatics.

Charles. You showed us yesterday that the stroke made by the clapper of a bell was not audible, when it was under an exhausted receiver; is the air the cause of sound?

Father. Certainly in many cases

it is: of this kind is thunder, the most awful sound in nature:—

> ——The air is vehicle of sound;
> Remove but the elastic pulse of air,
> And the same ear, which now delighted feels
> The nice distinction of the finest notes,
> Would not discern the thunder from a breeze.
>
> EUDOSIA.

Emma. Is thunder produced by the air?

Father. Thunder is generally supposed to be produced by the concussion or striking together of two bodies of air; for, lightning, darting through the air causes, by its great velocity, a vacuum, and the separated bodies of air, rushing together produce the noise we call thunder. The same effect, only in miniature, is produced by the inflammation of gunpowder.

Charles. Can the report of a large cannon be called a miniature imitation? I remember being once in a room at the distance of but a few paces from the Tower guns when they fired, and the noise was infinitely worse than any thunder that I ever heard.

Father. This was because you were near them: gunpowder, so tremendous as it is in air, when inflamed in a *vacuum* makes no more sound than the bell in like circumstances.

Mr. Cotes mentions a very curious experiment, which was contrived to show that sound cannot penetrate through a vacuum. A strong receiver, filled with common atmospheric air, in which a bell was suspended, was screwed down to a brass plate so tight that no air could escape, and this was included in a much larger receiver. When the air between the two receivers was exhausted, the sound of the bell could not be heard.

Emma. Could it be heard before the air was taken away?

Father. Yes; and also the moment it was re-admitted.

Charles. What is the reason that some bodies sound so much better than others? Bell-metal is more musical than copper or brass, and these sound much better than many other substances.

Father. All sonorous bodies are elastic, the parts of which by percussion are made to vibrate: and as long as the vibrations continue, corresponding vibrations are communicated to the air, and these produce sound. Musical chords and bells are instances that will illustrate this.

Emma. The vibrations of the bell are not visible; and musical chords will vibrate after the sound has vanished.

Father. If light particles of dust be on the outside of a bell when it is struck, you will, by their motion, have no doubt but that the particles of the metal move too, though not sufficiently to be visible to the naked eye: and though the motion of a musical string continues after the sound ceases to be heard, yet it does not follow that sound is not still produced, but only that it is not sufficiently strong to produce a sensation in the ear. You see in a dark night the flash of a gun, but, being at a considerable distance from it, you hear no report. If, however, you knew that the light was occasioned by the inflammation of gunpowder in a musket or pistol, you would conclude that it was attended with sound, though it was not sufficiently strong to reach the place where you are.

Charles. Is it known how far sound can be heard?

Father. We are assured upon good authority, that the unassisted human voice has been heard at the distance of 10 or 12 miles; namely, from New to Old Gibraltar. And in the famous sea fight between the English and Dutch, in 1672, the sound of cannon was heard at the distance of

200 miles from the place of action. —In both these cases the sound passed over water; and it is well known that sound may be always conveyed much farther along a smooth than an uneven surface.

Experiments have been instituted to ascertain how much water, as a conductor of sound, was better than land; and a person was heard to read very distinctly at the distance of 140 feet on the Thames, and on land he could not be heard farther than 76 feet.

Emma. Might not there be interruptions in the latter case?

Father. No noise whatever intervened by land, but on the Thames there was some occasioned by the flowing of the water.

Charles. As we were walking last

summer towards Hampstead, we saw a party of soldiers firing at a mark near Chalk Farm, and you desired Emma and me to take notice as we approached the spot, how much sooner the report was heard after we saw the flash, than it was when we first got into the fields.

Father. My intention was, that you should know, from actual experiment, that sound is not conveyed instantaneously, but takes a certain time to travel over a given space.

When you stood close to the place, did you not observe the smoke and hear the report at the same instant?

Emma. Yes, we did.

Father. Then you are satisfied that the light of the flash, and the report, are always produced together. The former comes to the eye with the velocity of light, the latter reaches the ear with the velocity with which sound travels: if then light travels faster than sound, you will, at any considerable distance from a gun that is fired, see the flash before you hear the report. Do you know with what velocity light travels?

Charles. At the rate of 12 millions of miles in a minute*.

Father. With regard then to several hundred yards, or even a few miles, the motion of light may be considered as instantaneous: that is, there would be no assignable difference of time to two observers, one of whom should stand at the breech

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* See Vol. II, of Astronomy, Conver. XXVI.

of the gun, and the other at the distance of six, or eight, or ten miles from it.

Emma. This I understand, because 10 miles is as nothing when compared with 12 millions.

Father. Now sound travels only at the rate of about 13 miles in a minute; therefore, as time is easily divisible into seconds, the progressive motion of sound is readily marked by means of a stop-watch; consequently, if persons situated, some close to a gun when it is discharged, others at a quarter of a mile from it, and others at half a mile, and so on, they will all see the flash or smoke at the same instant, but the report will reach them at different times.

Charles. Is it certain that sounds of all kinds travel at this rate?

Father. A great variety of experiments have been made on the subject, and it seems now generally agreed that sound travels with a velocity that is equal to 1142 feet in a second of time.

Emma. Then with a stop-watch you could have told how far we were from the firing when we first saw it.

Father. Most easily: for I should have counted the number of seconds that elapsed between the flash and the report, and then have multiplied 1142 by the number, and I should have had the exact distance in feet between us and the gun.

Charles. Has this knowledge been applied to any practical purpose?

Father. It has frequently been used at sea, by night, to know the distance of a ship that has fired her watch-guns. Suppose you were in a vessel, and saw the flash of a gun, and between that and the report 24 seconds elapsed, what would be the distance of one vessel from another?

Emma. I should multiply 1142 by 24, and then bring the product into miles, which in this instance is equal to something more than five miles.

Father. The mischief occasioned by lightning is supposed to depend much on the distance at which the storm is from the spot from whence it is seen.

By counting the number of seconds elapsed between the flash of lightning and the clap of thunder, you may ascertain how far distant you are from the storm.

Charles. I should like to have a stop-watch to be able to calculate this for myself.

Father. As it will, probably, be some time before you become possessed of this expensive instrument, I will tell you of something which you have always about you, and which will answer the puspose.

Emma. What is that, papa?

Father. The pulse at your wrist, which, in healthy people, generally beats about 75 times in a minute*: in the same space of time sound flies 13 miles; therefore, in one pulsation sound passes over 13 miles divided by 75, that is about 915 feet, or the $\frac{1}{6}$th part of a mile, consequently in six pulsations it will pass over a mile.

Emma. If I see a flash of light-

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* In children the pulse is more rapid.

ning, and between that and the thunder I count at my wrist 36 or 60 pulsations, I say the distance in one case is equal to six miles, in the other ten: because, if sound travel $\frac{1}{6}$th of a mile in the interval between two pulsations at the wrist, it will travel $\frac{36}{6}=6$ miles, during 36 pulsations; and $\frac{60}{6}=10$ miles, during 60 pulsations.

Father. You are right; and this method will, for the present, be sufficiently accurate for all your purposes.

CONVERSATION XII.

Of the Speaking-Trumpet.

CHARLES. I have been thinking about the nature of sound, and am ready to ask what it is; I can conceive of particles of light issuing from the sun, or other luminous bodies, but I know not what sound is.

Father. It would be but of little use to give you a definition of sound, but I will endeavour to illustrate the subject. Sound is not a body like light, but it depends on the concussion or striking together of other bodies that are elastic, which being put into a tremulous motion, excite a wave in the surrounding air.

Emma. Is it such a wave as we see in the pond when it is ruffled by the wind?

Father. Rather such a one as is produced by throwing a pebble into still water.

Charles. I have often observed this; the surface of the water forms itself into circular waves.

Father. It is probable that the tremulous motion of the parts of a sonorous body communicate undulations in the air in a similar manner. Two obvious circumstances must strike every observer with regard to the undulations in water. (1.) The waves, the farther they proceed from the striking body, become less and less, till, if the water be of a sufficient magnitude, they become invisible, and die away. The same thing takes place with regard to sound; the farther a person is from the sounding body, the less plain it is heard, till at length the distance is too great for it to be audible; and (2.) the waves on the water are not propagated instantaneously, but are formed one after another in a given space of time. This, from what we have already shown, appears to be the manner in which sound is propagated.

Emma. Is sound the effect which is produced on the ear by the undulations of the air?

Father. It is: and according as these waves are stronger or weaker, the impression, and consequently the sensation, is greater or less. If sound be impeded in its progress by a body that has a hole in it, the waves pass through the hole, and then diverge on the other side as from a centre. Upon this principle the *speaking-trumpet* is constructed.

Charles. What is that, Sir?

Father. It is a long tube, used for the purpose of making the voice heard at a considerable distance:—the length of the tube is from 6 to 12 or 15 feet, it is straight throughout, having at one end a large aperture, and the other terminates in a proper shape and size to receive the lips of the speaker.

Emma. Are these instruments much in use?

Father. It is believed that they were more used formerly than now: they are certainly of great antiquity.

Alexander the Great made use of such a contrivance to communicate his orders to the army; by means of which it is asserted he could make himself perfectly understood at the distance of 10 or 12 miles. Stentor is celebrated by Homer as one who could call louder than fifty men:—

Heav'n's empress mingles with the mortal crowd,
And shouts, in STENTOR's sounding voice, aloud:
Stentor the strong, endu'd with *brazen lungs*,
Whose throat surpass'd the force of fifty tongues.

POPE's HOMER, b. v, l. 976.

From Stentor the speaking-trumpet has been called the stentorophonic tube.

Charles. Perhaps Stentor was employed in the army for the purpose of communicating the orders of the general, and he might make use of a trumpet for the purpose, and that is what is meant by brazen lungs.

Father. That is not an improbable conjecture. Well, besides speaking-trumpets, there are others contrived for assisting the hearing of deaf persons, which differ but little from the speaking-trumpet.

If A and B (Plate II, Fig. 24) represent two trumpets, placed in an exact line at the distance of 40 feet or more from one another, the smallest whisper at *a* would be heard distinctly at *b*; so that by a contrivance to conceal the trumpets, many of those speaking figures are constructed, which are frequently exhibited in the metropolis and other large towns.

Emma. I see how it may be done;

there must be two sets of trumpets, the one connected with the ear of the image into which the spectator whispers, and which conveys the sound to a person in another room, who, by tubes connected with the mouth of the image, returns the answer.

Father. Dr. Young, in his Lectures on Natural Philosophy, says, that the exhibition of the invisible girl is performed by conveying the sound through pipes, artfully concealed, and opening opposite to the mouth of the trumpet, from which it seems to proceed.

Charles. How are the lips set in motion?

Father. Very easily, by means of a string or wire passing under the floor up the body of the image.

CONVERSATION XIII.

Of the Echo.

FATHER. Let us turn our attention to another curious subject relating to sound, and which depends on the air; I mean the echo.

Emma. I have often been delighted to hear my own words repeated, and I once asked Charles how it happened, that if I stood in a particular spot in the garden, and shouted loud, my words were distinctly repeated; whereas if I moved a few yards nearer to the wall I had no answer. He told me that he knew nothing more than this, that in a part of Ovid's Metamorphoses, ECHO is represented as having been a nymph of the woods, but that, pining away in love, her voice was all that was left of her.

Charles. I did; and you shall hear a translation of the whole passage:—

So wondrous are th' effects of restless pain,
That nothing but her voice and bones remain,
Nay, ev'n the very bones at last are gone,
And metamorphos'd to a thoughtless stone!
Yet still the voice does in the wood survive;
The form's departed, but the sound's alive.

Emma. But these lines say nothing of Echo being a nymph.

Charles. Well, then, here are others applied immediately to Echo:—

A nymph she was, though only now a *sound*,
Yet of her tongue no other use was found
Than now she has; which never could be more
Than to repeat what she had heard before.

Father. I doubt this will give your sister but little satisfaction respecting the cause of the echo, which she has often heard, and which she may still hear in the garden.

Emma. No, I cannot conceive why a nymph of the woods should take up her residence in our garden, and the more so as I never saw her.

Father. If she is a mere sound, you cannot see her: I will endeavour to explain the subject. When you throw a pebble into a small pool of water, what happens to the waves when they reach the margin?

Charles. They are thrown back again.

Father. The same happens with regard to the undulations in the air, which are the cause of sound. They strike against any surface fitted for the purpose, as the side of a house, a brick wall, a hill, or even against trees, and are reflected or beat back again: this is the cause of an echo.

Emma. I wonder then that we do not hear echoes more frequently.

Father. There must be several concurring circumstances before an echo can be produced. For an echo to be heard, the ear must be in the *line of reflection.*

Charles. I do not know what you mean by the line of reflection.

Father. I cannot always avoid using terms that have not been previously explained. This is an instance. I will, however, explain what is meant by the line of incidence, and the line of reflection. When you come to Optics, these subjects will be made very familiar to you. You can play at marbles?

Charles. Yes, and so can Emma.

Father. It is not a very common amusement for girls; however, as it happens, I shall find my advantage in it, as she will the more readily enter into my explanation.

Suppose you were to shoot a marble against the wainscot, what would happen?

Charles. That depends on the direction in which I shoot it: if I stand directly opposite to the wainscot, the marble will, if I shoot it strong enough, return to my hand.

Father. The line which the marble describes in going to the wall, is called the *line of incidence*, and that which it makes in returning is the *line of reflection.*

Emma. But they are both the same.

Father. In this particular instance they are so: but suppose you shoot obliquely or sideways against the board, will the marble return to the hand?

Charles. O no! it will fly off sideways in a contrary direction.

Father. There the line it describes *before the stroke*, or the line of incidence, is different from that of reflection, which it makes *after the stroke.* I will give you another instance: if you stand before the looking-glass you see yourself, because the rays of light flow from you, and are reflected back again in the same line. But let Emma stand on one side of the room, and you on the other:—you both see the glass at the upper end of the room.

Emma. Yes, and I see Charles in it too.

Charles. I see Emma, but I do not see myself.

Father. This happens just like the marble which you shot sideways. The rays flow from Emma obliquely on the glass, upon which they strike, and fly off in a contrary direction, and by them you see her. I will apply this to sound.—If a bell *a* (Plate III, Fig. 25) be struck, and the undulations of the air strike the wall *c d* in a perpendicular direction, they will be reflected back in the same line; and if a person were properly situated between *a* and *c*, as at *x*, he would hear the sound of the bell by means of the undulations as they went to the wall, and he would hear it again as they came back, which would be the echo of the first sound.

Emma. I now understand the distinction between the direct sound and the echo.

Father. If the undulations strike the wall obliquely, they will, like the marble against the wainscot, or the rays of light against the glass, fly off again obliquely on the other side, in a reflected line, as *c m*: now if there be a hill or other obstacle between the bell and the place *m* where a person happens to be standing, he will not hear the direct sound of the bell, but only the echo of it, and to him the sound will come along the line *c m*.

Charles. I have heard of places where the sound is heard repeated several times.

Father. This happens where there are a number of walls, rocks, &c., which reflect the sound from one to the other; and where a person happens to stand in such a situation as to intercept all the lines of reflection. These are called tautological, or babbling echoes:—

> ——— Babbling echo mocks the hounds,
> Replying shrilly to the well tun'd horns,
> As if a double hunt were heard at once.
>
> SHAKESPEARE.

There can be no echo unless the direct and reflected sounds follow one another at a sufficient interval of time; for if the latter arrive at the ear before the impression of the direct sound ceases, the sound will not be double, but only rendered more intense.

Emma. Is there any rule by which the time may be ascertained?

Father. Yes, there is; I will begin with the most simple case. If a person stand at *x* (Plate III, Fig. 25), in order that the echo may be distinct, the *difference* between the space *a x*, and *a c* added to *c x*, must be at least 127 feet.

Charles. The space through which the *direct* sound travels to a person is *a x*, and the whole direct line to the wall is *a c*, besides which it has to come back through *c x* to reach the person again. All this I comprehend: but why do you say 127 feet in particular?

Father. It is founded on this

principle. By experience it is known that about nine syllables can be articulately and distinctly pronounced in a second of time. But sound travels with the velocity of 1142 feet in a second, therefore in the ninth part of a second it passes over $\frac{1142}{9}$, or 127 feet nearly, and consequently the reflected sound, which is the echo, to be distinct, must travel over at least 127 feet more than the direct.

Emma. If *c d* in the figure represent the garden wall, how far must I be from it to hear distinctly any word I utter? Will 63 or 64 feet be sufficient, so that the whole space which the sound has to travel be equal in this case also to 127 feet?

Father. It must be something more than this, because the first sound rests a certain time on the ear, which should vanish before the echo returns, or it will appear a continuation of the former, and not a distinct sound: it is generally supposed that the distance must not be less then 70 or 72 feet; and this will give the distinct echo of one syllable only.

Charles. Must the distance be increased in proportion to the number of syllables that are to be repeated?

Father. Certainly; and at the distance of about 1000 or 1200 feet, 8 or 10 syllables, properly pronounced, will be distinctly repeated by the echo.

I will finish this subject tomorrow.

CONVERSATION XIV.

Of the Echo.

FATHER. The following are among the most celebrated echoes. At Rosneath, near Glasgow, there is an echo that repeats a tune played with a trumpet three times completely and distinctly. Near Rome there was one that repeated what a person said five times. At Brussels there is an echo that answers 15 times. At Thornbury Castle, Gloucestershire, an echo repeats 10 or 11 times very distinctly. Between Coblentz and Bingen an echo is celebrated as different from most others.

In common echoes the repetition is not heard till some time after hearing the words spoken or notes sung; in this the person who speaks or sings is scarcely heard, but the repetition is perceived very clearly, and in surprising varieties: the echo in some cases appears to be approaching, in others receding: sometimes it is heard distinctly, at others scarcely at all: one person hears only one voice, while another hears several. And, to mention but one more instance, in Italy, near Milan, the sound of a pistol is returned 56 times.

Emma. This is indeed

> To fetch shrill echoes from their hollow
> earth.

Father. The ingenious Mr. Derham applied the echo to measuring inaccessible distances.

Charles. How did he do this?

Father. Standing on the banks of the Thames, opposite Woolwich, he observed that the echo of a single sound was reflected from the houses in three seconds, consequently in that time it had travelled 3426 feet, the half of which, or 1713 feet, was the breadth of the river in that particular place.

Did you ever hear of the Whispering-Gallery in the dome of St. Paul's Church?

Emma. Yes: and you promised to take us to see it some time.

Father. And I will perform my promise. In the mean time it may be proper to inform you, that the circumstance that attracts every person's attention is that the smallest whisper made against the wall on one side of the gallery is distinctly heard on the other side.

Charles. Is this effect produced on the principle of the echo?

Father. No: the undulations caused in the air by the voice are reflected both ways round the wall, which is made very smooth, so that none may be lost, and meet at the opposite side; consequently, to the hearer, the sensation is the same as if his ear were close to the mouth of the speaker.

Emma. Would the effect be the same if the two persons were not opposite to one another?

Father. In that case the words spoken would be heard double, because one arch of the circle being less than the other, the sound will arrive at the ear sooner round the shorter arch than round the longer one.

Charles. You said the wall is very smooth: is there a material difference, in the conveyance of sound, whether the medium be rough or smooth?

Father. The difference is very great. Still water is, perhaps, the best conductor of sound: the echo which I mentioned, in the neighbourhood of Milan, depends much on the water over which the villa stands. Dr. Hutton, in his Mathematical Dictionary, gives the following instance, as a proof that moisture has a considerable effect upon sound. A house in Lambeth marsh is very damp during winter, when it yields an echo, which abates as soon as it becomes dry in summer. To increase the sound in a theatre at Rome, a canal of water was carried under the floor, which caused a great difference.

After water, stone is reckoned a good conductor of sound, though the tone is rough and disagreeable: a well-made brick wall has been known to convey a whisper to the distance of 200 feet nearly. Wood is sonorous, and produces the most agreeable tone, and is therefore the most proper substance for musical instruments: of these we shall say a word or two before we quit the subject of sound.

Emma. All wind instruments, as flutes, trumpets, &c., must depend on the air: but do stringed instruments?

Father. They all depend on the vibrations which they make in the surrounding air. I will illustrate what I have to say by means of the Eolian harp.

If a cord eight or ten yards long be stretched very tight between two points, and then struck with a stick, the whole string will not vibrate, but there will be several still places in it, between which the cord will move. Now the air acts upon the strings of the Eolian harp in the same manner as the stroke of the stick upon the long cord just mentioned.

Charles. Do not the different notes upon a violin depend upon the different length of the strings, which is varied by the fingers of the musician?

Father. They do: and the current of air acts upon each string, and divides it into parts, as so many imaginary bridges. Hence every string in an Eolian harp, though all are in unison, become capable of several sounds, from which arises the wild and wonderful harmony of that instrument.

The undulations of the air, caused by the quick vibrations of a string, are well illustrated by a sort of mechanical sympathy that exists among accordant sounds. If two strings on different instruments are tuned in unison, and one be struck, the other will reply, though they be several feet distant from one another.

Emma. How is this accounted for?

Father. The waves made by the first string being of the same kind as would be made by the second if struck, those waves give a mechanical stroke to the second string, and produce its sound.

Charles. If all the strings on the Eolian harp are set to the same note, will they all vibrate by striking only one?

Father. They will: but the fact is well illustrated in this method: bend little bits of paper over each string, and then strike one sufficiently to shake off its paper, and you will see the others will fall from their strings.

Emma. Will not this happen if the strings are not in unison?

Father. Try for yourself; alter the notes of all the strings but two, and place the papers on again: vibrate that string which is in unison with another.

Emma. The papers on those are shaken off; but the others remain.

Father. A wet finger pressed round the edge of a thin drinking glass will produce its key: if the glass be struck so as to produce its pitch, and an unison to that pitch be strongly excited on a violoncello, the glass will be set in motion, and if near the edge of the table will be liable to be shaken off.

On the same principle the harmonical glasses are constructed, which are said to produce sweeter tones than can be had from any other instrument, and that may be swelled and softened at pleasure by different pressures of the finger.

CONVERSATION XV.

Of the Winds.

FATHER. You know, my children, what the wind is?

Charles. You told us, a few days ago, that you should prove it was only the air in motion.

Father. I can show you in miniature, that air in motion will produce effects similar to those produced by a violent wind.

I place this little mill under the receiver of the air-pump in such a manner, that the air, when re-entering, may catch the vanes. I will exhaust the air;—now observe what happens when the stop-cock is opened.

Emma. The vanes turn round with an incredible velocity; much swifter than ever I saw the vanes of a real windmill. But what puts the air in motion, so as to cause the wind?

Father. There are, probably, many conspiring causes to produce the effect. The principal one seems to be heat communicated by the sun.

Charles. Does heat produce wind?

Father. Heat, you know, expands all bodies; consequently it rarefies the air, and makes it lighter. But you have seen that the lighter fluids ascend, and thereby leave a partial vacuum, towards which the surrounding heavier air presses, with a greater or less quantity of motion, according to the degree of rarefaction, or of heat which produces it. The air of this room, by means of the fire, is much warmer than that in the passage.

Emma. Has that in the passage a tendency into the parlour?

Father. Take this lighted wax taper, and hold it at the bottom of the door.

Emma. The wind blows the flame violently into the room.

Father. Hold it now at the top of the door.

Charles. The flame rushes outwards there.

Father. This simple experiment deserves your attention. The heat of the room rarefies the air, and the lighter particles ascending, a partial vacuum is made at the lower part of the room; to supply the deficiency, the dense, outward air rushes in, while the lighter particles, as they ascend, produce a current at the top of the door out of the room. If you hold the taper about the middle space, between the bottom and top, you will find a part in which the flame is perfectly still, having no tendency either inwards or outwards.

The *smoke-jack*, so common in the chimneys of large kitchens, consists of a set of vanes, something like those of a windmill or ventilator, fixed to wheel-work, which are put in motion by the current of air up the chimney, produced by the heat of the fire, and of course the force of the jack depends on the strength of the fire, and *not* upon the quantity of smoke, as the name of the machine would lead you to suppose.

Emma. Would you define the wind as a current of air?

Father. That is a very proper definition: and its direction is denominated from that quarter from which it blows.

Charles. When the wind blows from the north or south, do you say it is in the former case a north wind, and in the latter a south wind?

Father. We do. The winds are generally considered as of three kinds, independently of the names which they take from the points of the compass from which they blow. These are the *constant*, or those which always blow in the same direction: the *periodical*, or those which blow six months in one direction, and six in a contrary direction: and the *va-*

riable, which appear to be subject to no general rules.

Emma. Is there any place where the wind always blows in one direction only?

Father. This happens to a very large part of the earth; to all that extensive tract that lies between 28 or 30 degrees north and south of the equator.

Charles. What is the cause of this?

Father. If you examine the globe, you will see* that the apparent course of the sun is from east to west, and that it is always vertical to some part of this tract of our globe; and, since the wind follows the sun, it

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* It is supposed the reader is acquainted with the second volume of the Scientific Dialogues.

must, of necessity, blow in one direction constantly.

Emma. And is that due east?

Father. It is only so at the equator: for on the north of this line the wind declines a little to the north point of the compass, and this the more so as the place is situated farther towards the north; on the south side the wind will be southerly.

Charles. The greater part of this tract of the globe is water; and I have heard you say, that transparent mediums do *not* receive heat from the sun.

Father. The greater part is certainly water; but the proportion of land is not small: almost the whole continent of Africa, a great part of Arabia, Persia, the East Indies, and China, besides the whole nearly of

New Holland, and numerous islands in the Indian and Pacific oceans: and in the western hemisphere, by far the greatest part of South America, New Spain, and the West India islands, come within the limits of 30 degrees north and south of the equator. These amazingly large tracts of land imbibe the heat, by which the surrounding air is rarefied, and thus the wind becomes *constant*, or blows in one direction.

You will also remember, that neither the sea nor the atmosphere is so perfectly transparent as to transmit all the rays of the solar light; many are stopped in their passage, by which both the sea and air are warmed to a considerable degree. These constant or general winds are usually called *trade-winds*.

Emma. In what part of the globe do the *periodical* winds prevail?

Father. They prevail in several parts of the eastern and southern oceans, and evidently depend on the sun; for when the apparent motion of that body is north of the equator, that is, from the end of March to the same period in September, the wind sets in from the south-west; and the remainder of the year, while the sun is south of the equator, the wind blows from the north-east. These are called the monsoons, or shifting trade-winds, and are of considerable importance to those who make voyages to the East Indies.

Charles. Do these changes take place suddenly?

Father. No: some days before and after the change there are calms, variable winds, and frequently the most violent storms.

On the greater part of the coasts situated between the tropics the wind blows towards the shore in the day-time, and towards the sea by night. These winds are called sea and land breezes; they are affected by mountains, the course of rivers, tides, &c.

Emma. Is it the heat of the sun by day that rarefies the air over the land, and thus causes the wind?

Father. It is: the following easy experiment will illustrate the subject.

In the middle of a large dish of cold water put a water-plate filled with hot water: the former represents the ocean, the latter the land rarefying the air over it. Hold a lighted candle over the cold water, and blow it out; the smoke, you see, moves towards the plate. Reverse the experiment by filling the outer vessel with warm water, and the plate with cold, the smoke will move from the plate to the dish.

Charles. In this country there is no regularity in the direction of the winds; sometimes the easterly winds prevail for several days together, at other times I have noticed the wind blowing from all quarters of the compass two or three times in the same day.

Father. The variableness of the wind in this island depends probably on a variety of causes; for whatever destroys the equilibrium in the atmosphere, produces a greater or less current of wind towards the place where the rarefaction exists.

It is generally believed that the electric fluid, which abounds in the air, is the principal cause of the variableness of the wind here. You may often see one tier of clouds moving in a certain direction, and another in a contrary one; that is, the higher clouds will be moving perhaps north or east, while the weather-cock stands directly south or west. In cases of this kind a sudden rarefaction must have taken place in the regions of one set of these clouds, and consequently the equilibrium destroyed. This phenomenon is frequently found to precede a thunder storm; from which it has been supposed that the electric fluid is, in this and such like instances, the principal cause in producing the wind; and if in the more remarkable appearances we are able to trace the operating cause, we may naturally infer that those which are less so, but of the same nature, depend on a like principle.

Emma. Violent storms must be occasioned by sudden and tremendous concussions in nature. I remember to have seen once last year (1800) some very large trees torn up by the wind. It is difficult to conceive how so thin and light a body can produce such dire effects.

Father. The inconceivable rapidity of lightning will account for the suddenness of any storm; and when you are acquainted with what velocity a wind will sometimes move, you will not be surprised at the effects which it is capable of producing.

Charles. Is there any method of ascertaining the velocity of the wind?

Father. Yes; several machines

have been invented for the purpose. But Dr. Derham, by means of the flight of small downy feathers, contrived to measure the velocity of the great storm which happened in the year 1705, and he found that the wind moved 33 feet in half a second, that is, at the rate of 45 miles per hour: and it has been proved that the force of such a wind is equal to the perpendicular force of 10 pounds avoirdupois weight on every square foot. Now if you consider the surface which a large tree, with all its branches and leaves, presents to the wind, you will not be surprised, that in great storms, some of them should be torn up by the roots.

Emma. Is the velocity of 45 miles an hour supposed to be the greatest velocity of the wind?

Father. Dr. Derham thought the greatest velocity to be about 60 miles per hour: but we have tables calculated to show the *force* of the wind at all velocities from 1 to 100 miles per hour.

Charles. Does the *force* bear any general proportion to the velocity?

Father. Yes it does: the force increases as the *square* of the velocity.

Emma. Do you mean, that if on a piece of board, exposed to a given wind, there is a pressure equal to 1 pound, and the same board be exposed to another wind of *double* velocity, the pressure will be in this case 4 times greater than it was before?

Father. That is the rule. The following short table, selected from a larger one out of Dr. Hutton's

Dictionary, will fix the rule and facts in your memory.

TABLE.

Velocity of the wind, in miles, per hour.	Perpendicular force on one square foot in pounds avoirdupois.	Common appellations of the Winds.
5	.123	Gentle, pleasant wind.
10	.492	Brisk gale.
20	1.968	Very brisk.
40	7.872	Very high wind.
80	31.488	A hurricane.

NOTE.—Mr. Brice discovered, from observations on the clouds, or their shadows moving on the surface of the earth, that the velocity of wind in a storm was nearly 63 miles in an hour, 21 miles in a fresh gale, and nearly 10 miles in a breeze.

CONVERSATION XVI.

Of the Steam-Engine.

FATHER. If you understand the principle of the forcing-pump, you will easily comprehend in what manner the steam-engine, the most important of all hydrostatical machines, acts.

Charles. Why do you call it the most important of all machines? It is not a common one.

Father. Steam-engines can be used with advantage only in those cases where great power is required. They are adapted to the raising of water from ponds and wells; to the draining of mines; and perhaps without their assistance we should not at this moment have the benefit of coal fires.

Emma. Then there cannot be two opinions entertained respecting their utility. I do not know what we should do without them in winter, or even in summer, since coal is the fuel chiefly used in dressing our food.

Father. Our ancestors had, a century ago, excavated all the mines of coal as deep as they could be worked without the assistance of these sort of engines. For when the miners have dug a certain depth below the surface of the earth the water pours in upon them from all sides; consequently they have no means of going on with their work without the assistance of a steam-engine, which is erected by the side of the pit, and, being kept constantly at work, will keep it dry enough for all practical purposes.

The steam-engine was invented during the reign of Charles II, though it was not brought to a degree of perfection sufficient for the draining of mines till nearly half a century after that period.

Charles. To whom is the world indebted for the discovery?

Father. It is difficult, if not impossible, to ascertain who was the inventor. The marquis of Worcester described the principle in a small work entitled "A Century of Inventions," which was published in the year 1663, and was reprinted a few years since in London.

Emma. Did the marquis construct one of these engines?

Father. No; the invention seems to have been neglected for several years, when captain Thomas Savery, after a variety of experiments, brought it to some degree of perfection, by which he was able to raise water, in small quantities, to a moderate height.

Charles. Did he take the invention from the marquis of Worcester's book?

Father. Dr. Desaguliers, who, in the middle of the last century, entered at large into the discussion, maintains that captain Savery was wholly indebted to the marquis, and, to conceal the piracy, he charges him with having purchased all the books which contained the discovery, and burned them. Captain Savery, however, declared, that he was led to the discovery by the following accident:—“Having drank a flask of Florence wine at a tavern, and thrown the flask on the fire, he perceived that the few drops left in it were converted into steam: this induced him to snatch it from the fire, and plunge its neck into a bason of water, which, by the atmospheric pressure, was driven quickly into the bottle.”

Emma. This was something like an experiment which I have often seen at the tea-table. If I pour half a cup of water into the saucer, then hold a piece of lighted paper in the cup a few seconds, and when the cup is pretty warm, plunge it with the mouth downwards into the saucer, the water almost instantly disappears.

Father. In both cases, the principle is exactly the same: the heat of the burning paper converts the water that hung about the cup into steam, but steam, being much lighter than air, expels the air from the cup, which being plunged into the water, the steam is quickly condensed, and a partial vacuum is made in the cup; consequently the pressure of the atmosphere upon the water in the saucer forces it into the cup, just in the same manner as the water follows the vacuum made in the pump.

Charles. Is steam, then, used for the purpose of making a vacuum, instead of a piston?

Father. Just so: and Dr. Darwin ascribes to captain Savery the honour of being the first person who applied it to the purpose of raising water: —

Nymphs! YOU erewhile on simm'ring cal-
drons play'd,
And call'd delighted SAVERY to your aid,
Bade round the youth EXPLOSIVE STEAM aspire
In gath'ring clouds, and wing'd the wave with
fire;
Bade with cold streams the quick expansion
stop,
And sunk th' immense of vapour to a drop.
Press'd with the pond'rous air the piston falls
Resistless, sliding through its iron walls;
Quick moves the balanc'd beam, of giant birth,
Wields his large limbs, and nodding shakes
the earth.

Emma. I remember the lines very well: will you describe the engine, that we may see how they apply?

Father. I shall endeavour to give you a general and a correct explanation of the principle and mode of acting of one of Mr. Watt's engines, without entering into all the minutiæ of the several parts.

A (Plate IV, Fig. 35) is a section of the boiler, standing over a fire, about half full of water: B is the steam-pipe which conveys the steam from the boiler to the cylinder C, in which the piston D, made air-tight, works up and down: *a* and *c* are the steam valves, through which the steam enters into the cylinder; it is admitted through *a* when it is to force the piston downwards, and through *c* when it presses it upwards: *b* and *d* are the eduction valves, through which the steam passes from the cylinder into the condenser *e*, which is a separate vessel placed in a cistern of cold water, and which has a jet of cold water continually playing up in the inside of it: *f* is the air pump, which extracts the air and water from the condenser; it is worked by the great beam or lever R S, and the water taken from the condenser, and thrown into the hot well *g*, is pumped up again by means of the pump *y*, and carried back into the boiler by the pipe *i i*: *k* is another pump, likewise worked by the engine itself, which supplies the cistern, in which the condenser is fixed, with water.

Charles. Are all three pumps, as well as the piston, worked by the action of the great beam?

Father. They are; and you see the piston-rod is fastened to the beam by inflexible bars; but that the stroke might be perpendicular, Mr. Watt invented the machinery called the parallel joint, the construction of which will be easily understood from the figure.

Emma. How are the valves opened and shut?

Father. Long levers *o* and *p* are attached to them, which are moved up and down by the piston-rod of the air-pump E F. In order to communicate a rotatory motion to any machinery by the motion of the beam, Mr. Watt makes use of a large fly-wheel X, on the axis of which is a small concentric toothed wheel H; a similar toothed wheel I is fastened to a rod T coming from the end of the beam, so that it cannot turn on its axis, but must rise and fall with the emotion of the great beam.

A bar of iron connects the centres of the two small toothed wheels; when, therefore, the beam raises the wheel I, it must move round the circumference of the wheel H, and with it turn the fly-wheel X; which will make two revolutions while the wheel I goes round it once. These are called the Sun and Planet wheels; H, like the sun, turns only on its axis, while I revolves about it as the planets revolve round the sun.

If to the centre of the fly-wheel any machinery were fixed, the motion of the great beam R S would keep it in constant work.

Charles. Will you describe the operation of the engine?

Father. Suppose the piston at the top of the cylinder, as it is represented in the plate, and the lower part of the cylinder filled with steam. By means of the pump-rod E F, the steam valve *a* and the eduction valve *d* will be opened together, the branches from which being connected at *o*. There being now a communication at *d* between the cylinder and condenser, the steam is forced from the former into the latter, leaving the lower part of the cylinder empty, while the steam from the boiler entering by the valve *a* presses upon the piston, and forces it down. As soon as the piston has arrived at the bottom, the steam valve *c* and the eduction valve *b* are opened, while those at *a* and *d* are shut; the steam, therefore, immediately rushes through the eduction valve *b* into the condenser, while the piston is forced up again by the steam, which is now admitted by the valve *c*.

Hence, you observe, that the steam is condensed, in a separate vessel, for the purpose of forming a vacuum under the piston: the force of steam is also introduced above the piston to depress it, an operation that was formerly done by the pressure of the atmosphere.

CONVERSATION XVII.

Of the Steam-Engine.

CHARLES. I do not understand how the two sets of valves act, which you described yesterday, as the steam and eduction valves.

Father. If you look to Fig. 36, Plate IV, there is a different view of this part of the machine, unconnected with the rest: *s* is part of the pipe which brings the steam from the boiler: *a* represents the valve, which, being opened, admits the steam into the upper part of the cylinder, forcing down the piston.

Emma. Is not the valve *d* opened at the same time?

Father. It is: and then the steam which was under the piston is forced through into the condenser *e*. When the piston arrives at the bottom, the other pair of valves are opened, *viz.* *c* and *b*; through *c* the steam rushes to raise the piston, and through *b* the steam, which pressed the piston down before, is driven out into the pipe *r*, leading to the condenser; in this there is a jet of cold water constantly playing up, and thereby the steam is instantly reduced into the shape of hot water.

Charles. Then the condenser *e* (Fig. 35) will soon be full of water.

Father. It would, if it were not connected by the pipe *z* with the pump *f*: and every time the great beam R S is brought down, the plunger, at the bottom of the piston-rod E F, descends to the bottom of the pump.

Emma. Is there a valve in the plunger?

Father. Yes, which opens upwards, consequently all the hot water which runs out of the condenser into the pump, will escape through the valve, and be at the top of the plunger, and the valve not admitting it to return, it will, by the ascent of the piston-rod into the situation as is shown in the plate, be driven through *n* into *g*, the cistern of hot water, from which, owing to a valve, it cannot return.

Charles. And I see the same motion of the great beam puts the pump *y* in action, and brings over the hot water from the cistern *g*, through the pipe *i i* into the little cistern v, which supplies the boiler.

Emma. If the pump *k* brings in, by the same motion, the water from the well w, do not the hot and cold water intermix?

Father. No: if you look carefully in the figure, you will observe a strong partition v, which separates the one from the other. Besides, you may perceive that the hot water does not stand at so high a level as the cold, which is a sufficient proof that they do not communicate. Indeed the operation of the engine would be greatly injured, if not wholly stopped, if the hot water communicated with the cold; as in that case the water, being at a medium heat, would be too warm to condense the steam in *e*, and too cold to be admitted into the boiler without checking the production of the steam.

Charles. There are some parts of the apparatus belonging to the boiler which you have not yet explained. What is the reason that the pipe *q*, which conveys the water from the cistern v to the boiler, is turned up at the lower end.

Father. If it were not bent in that manner, the steam that is generated at the bottom of the boiler would rise into the pipe, and in a great measure prevent the descent of the water through it.

Emma. In this position I see clearly no steam can enter the pipe, because steam, being much lighter than water, must rise to the surface, and cannot possibly sink through the bended part of the tube. What does *m* represent?

Father. It represents a stone suspended on a wire, which is shown by the dotted line: this stone is nicely balanced by means of a lever, to the other end of which is another wire, connected with a valve at the top of the pipe *q*, that goes down from the cistern.

Charles. Is the stone so balanced as to keep the valve sufficiently open to admit a proper quantity of water?

Father. It is represented by the figure in that situation. By a principle in hydrostatics*, with which you are are acquainted, the stone is partly supported by the water; if then, by increasing the fire, too great

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* See Vol. III, on Hydrostatics, Conver. XI.

an evaporation take place, and the water in the boiler sink below its proper level, the stone also must sink, which will cause the valve to open wider, and let that from the cistern come in faster. If, on the other hand, the evaporation be less than it ought to be, the water will have a tendency to rise in the boiler, and with that the stone must rise, and the valve will, consequently, let the water in with less velocity. By this neat contrivance, the water in the boiler is always kept at one level.

Emma. What are the pipes *t* and *u* for?

Father. They are seldom used, but are intended to show the exact height of the water in the boiler. The one at *t* reaches very nearly to the surface of the water when it is at the proper height: that at *u* enters a little below the surface. If then the water be at its proper height, and the cocks *t* and *n* be opened, *steam* will issue from the *former*, and *water* from the *latter*. But if the water be too *high*, it will rush out at *t* instead of steam: if too *low*, the steam will issue out of *u* instead of water.

Charles. Suppose things to be as represented in the plate, why will the water rush out of the cock *u* if it be opened? it will not rise above its level.

Father. True: but you forget that there is a constant pressure of the steam on the surface of the water in the boiler, which tends to raise the water in the pipe *u*. This pressure would force the water through the pipe, as in an artificial fountain.—See p. 73 and 74.

Emma. You said Captain Savery was the inventor of the steam-engine.

Father. His invention went merely to raising water from pits and mines. But, in its present improved state, the steam-engine is applied to a thousand useful and important purposes.

NOTE.—In the next Conversation will be given an account of the purposes to which the steam-engine is applied. But perhaps one of the most striking exhibitions of the wonderful effects of this machine is to be seen in that part of the Portsmouth dockyard in which the blocks for ships are made. These blocks are completely finished from the rough timber, with scarcely any manual labour, by means of different saws and other tools worked by the steam-engine.

CONVERSATION XVIII.

Of the Steam-Engine, and Papin's Digester.

CHARLES. We have seen the structure of the steam-engine and its mode of operation; but you have not told us the uses to which it is applied.

Father. The application of this power was at first wholly devoted to the raising of water, either from the mines, which could not be worked without such aid, or to the throwing it to some immense reservoir, for the purpose of supplying, with this useful article, places which are higher than the natural level of the stream.

Emma. Is it to this that Dr. Darwin alludes in the lines,

Here high in air the rising stream he pours,
To clay-built cisterns, or to lead-lin'd tow'rs;
Fresh through a thousand pipes the waves distils,
And thirsty cities drink th' exuberant rills.

Father. It is; and you might have repeated the whole passage, in which the steam-engine, represented as a giant-power, is supposed applicable to the bringing up of the coals and other ore from the mine, and to the working of the bellows at the furnace, in which the ore is melted:—

Fan the white flame, and fuse the sparkling ore.

The author refers also to the application of this engine to various other purposes, such as the working of mills, the threshing of corn, and coining. In making the copper money now in use, the ingenious Mr. Boulton has contrived, by a single operation of the steam-engine, to roll the copper out to a proper thickness, to cut it into circular pieces, and to make the faces and the edge.

Charles. How is the power of these engines estimated?

Father. The power varies according to the size. That at Messrs. Whitbread's brewhouse, to which I have had access through the kindness of Mr. Timothy Brown, a gentleman well known for his liberality, and attachment to men of science and literature, has a cylinder 24 inches in diameter, and will perform the work of 24 horses, working night and day.

Emma. But the horses cannot work incessantly.

Father. They will work only eight hours, at the average, out of the 24; therefore, since the engine is kept continually at work, it will perform the business of 72 horses. The coals consumed by this engine are about 7 chaldron per week, or 1 chaldron in 24 hours.

By the application of different machinery to this engine, it raises the malt into the upper warehouses, and grinds it; it pumps the wort from the under-backs into the copper; raises the wort into the coolers; it fills the barrels when the beer is made; and, when the barrels are full and properly bunged, they are, by the steam-engine, driven into the store-houses in the next street, a distance of more than a hundred yards, and let down into the cellar.

Charles. I do not wonder, then, that Dr. Darwin should anticipate the still farther extension of this useful power: —

Soon shall thy arm, *unconquer'd steam!* afar
Drag the slow barge, or drive the rapid car;
Or on wide waving wings expanded bear
The flying chariot through the fields of air.
Fair crews triumphant, leaning from above,
Shall wave their flutt'ring kerchiefs as they
move,
Or warrior-bands alarm the gaping croud,
And armies shrink beneath the shadowy cloud.

Emma. Why does Dr. Darwin, in the passage you quoted the other day, call it *explosive* steam?

Father. From a great variety of accidents that have happened through careless people, it appears that the expansive force of steam, suddenly raised, is much stronger than even that of gunpowder. At the cannon foundery in Moorfields, some years ago, hot metal was poured into a mould that accidentally contained a small quantity of water, which was instantly converted into steam, and caused an explosion that blew the foundery to pieces. A similar accident happened at a foundery in Newcastle, which occurred from a little water having insinuated itself into a hollow brass ball that was thrown into the melting pot.

Charles. These facts bring to my mind a circumstance that I have often heard you relate, as coming within your knowledge.

Father. You do well to remind me

of it. The fact is worth recording. A nobleman, who was carrying on a long series of experiments, wished to ascertain the strength of a copper vessel, and gave orders to his workmen for the purpose. The vessel, however, burst unexpectedly, and in the explosion, it beat down the brick wall of the building in which it was placed, and was, by the force of the steam, carried 15 or 20 yards from it; several of the bricks were thrown 70 yards from the spot; a leaden pipe, suspended from an adjoining building, was bent into a right angle; and several of the men were so dreadfully bruised, or scalded, that for many weeks they were unable to stir from their beds. A very intelligent person, one of the sufferers, who conducted the experiment, assured me, that he had not the smallest recollection how the accident happened, or by what means he got to his bed-room after the explosion.

Emma. Is it by the force of steam that bones are dissolved in Papin's Digester, which you promised to describe*?

Father. No; that operation is performed by the great heat produced in the digester. Plate III, Fig. 26, is a representation of one of these machines. It is a strong metal pot, at least an inch thick in every part; the top is screwed down, so that no steam can escape but through the valve v.

Charles. What kind of a valve is it?

Father. It is a conical piece of

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* See Vol. I, of Mechanics, Conver. III.

brass, made to fit very accurately, but easily moveable by the steam of the water when it boils: consequently, in its simple state, the heat of the water will never be much greater than that of boiling water in an open vessel. A steel-yard is therefore fitted to it, and, by moving the weight w backwards or forwards, the steam will have a lesser or greater pressure to overcome.

Emma. Is the heat increased by confining the steam?

Father. You have seen, that, in an exhausted receiver, water not near so hot as the boiling point, will have every appearance of ebullition. It is the pressure of the atmosphere that causes the heat of boiling water to be greater in an open vessel, than in one from which the air is exhausted.

In a vessel exposed to condensed air, the heat required to make the water boil would be still greater. Now, by confining the steam, the pressure may be increased to any given degree. If, for instance, a force equal to 14 or 15 pounds be put on the valve, the pressure upon the water will be double that produced by the atmosphere, and of course the heat of the water will be greatly increased.

Charles. Is there no danger to be apprehended from the bursting of the vessel?

Father. If care be taken so as not to load this valve too much, the danger is not very great. But in experiments made to ascertain the strength of any particular vessel, the utmost precautions must be taken.

Under the direction of Mr. Papin,

the original inventor, the bottom of a digester was torn off with a wonderful explosion: the blast of the expanded water blew all the coals out of the fire-place, the remainder of the vessel was hurled across the room, and striking the leaf of an oaken table an inch thick, broke it in pieces. The least sign of water could not be discerned, and every coal was extinguished in a moment.

CONVERSATION XIX.

Of the Barometer.

FATHER. As these Conversations are intended to make you familiar with all those philosophical instruments that are in common use, as well as to explain the use and structure of those devoted to the teaching of science, I shall proceed with an account of the barometer, which, with the thermometer, is to be found in almost every house. I will show you how the barometer is made, without any regard to the frame to which it is attached, A B (Plate III, Fig. 27) is a glass tube, about 33 or 34 inches long, closed at top; that is, in philosophical language, *hermetically sealed;* D is a cup, bason, or wooden trough, partly filled with quicksilver. I fill the tube with the quicksilver, and then put my finger upon the mouth, so as to prevent any of it from running out: I now invert the tube, and plunge it in the cup D. You see the mercury subsides three or four inches; and when the tube is fixed to a graduated frame it is called a barometer, or weather glass, and you know it is consulted by those who study and attend to the changes of the weather.

Emma. Why does not all the quicksilver run out of the tube?

Father. I will answer you, by asking another question: What is the reason that water will stand in an exhausted tube, providing the mouth of it be plunged into a vessel of the same fluid?

Charles. In that case the water is kept in the tube by the pressure of the atmosphere on the surface of the water into which it is plunged. If you resort to the same principle, in the present instance, why does the water stand 33 or 34 *feet*, but the mercury only 29 or 30 inches?

Father. Do you not recollect that mercury is 14 times heavier than water? therefore, if the pressure of the atmosphere will balance 34 feet of water, it ought, on the same principle, to balance only a 14th part of that height of mercury: now divide 34 feet, or 408 inches, by 14.

Emma. The quotient is little more than 29 inches.

Father. By this method Torricelli was led to construct the barometer. It had been accidently discovered that water could not be raised more than about 34 feet in the pump. Torricelli, on this, suspected that the pressure of the atmosphere was the cause of the ascent of water in the vacuum made in pumps, and that a column of water 34 feet high was an exact counterpoise to a column of air which extended to the top of the atmosphere. Experiments soon confirmed the truth of his conjectures. He then thought, that, if 34 feet of water were a counterpoise to the pressure of the atmosphere, a column of mercury, as much shorter than 34 feet as mercury is heavier than water, would likewise sustain the pressure of the atmosphere: he obtained a glass tube for the purpose, and found his reasoning just.

Charles. Did he apply it to the purpose of a weather glass?

Father. No: it was not till some time after this that the pressure of the air was known to vary at different times in the same place. As soon as that was discovered, the application of the Torricellian tube to predicting the changes of the weather immediately succeeded.

Charles. A barometer, then, is an instrument used for measuring the weight or pressure of the atmosphere.

Father. That is the principal use of the barometer: if the air be *dense*, the mercury rises in the tube, and indicates fair weather: if it grows *light*, the mercury falls, and presages rain, snow, &c.*

The height of the mercury in the tube is called the *standard altitude*, which in this country fluctuates between 28 and 31 inches, and the difference between the greatest and least altitude is called the *scale of variation.*

Emma. Is the fluctuation of the mercury different in other parts of the world?

Father. Within and near the tropics there is little or no variation in the height of the mercury in the barometer in all weathers: this is the case at St. Helena. At Jamaica the variation very rarely exceeds three-

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* See the rules at the end of the volume.

tenths of an inch: at Naples it is about one inch: whereas in England it is nearly three inches, and at Petersburg it is as much as $3\frac{1}{2}$ inches.

Charles. The scale of variation is the silvered plate, which is divided into inches and tenths of an inch: but what do you call the moveable index?

Father. It is called a *vernier*, from the inventor's name, and the use of it is to show the fluctuation of the mercury to the hundredth part of an inch. The scale of inches is placed on the right side of the barometer tube, the beginning of the scale being the surface of the mercury in the bason: the vernier plate and index are moveable, so that the index may, at any time, be set to the upper surface of the column of mercury.

Emma. I have often seen you move the index, but I am still at a loss to conceive how you divide the inch into hundredth parts by it.

Father. The barometer plate is divided into tenths; the length of the vernier is eleven tenths, but divided into ten equal parts.

Charles. Then each of the ten parts is equal to a tenth of an inch, and a tenth part of a tenth.

Father. True: but the tenth part of a tenth is equal to a hundredth part, for you remember that to divide a fraction by any number is to multiply the denominator of the fraction by the number, thus $\frac{1}{10}$ divided by $10=\frac{1}{100}$.

Suppose the index of the vernier to coincide exactly with one of the divisions of the scale of variation, as 29.3.

Emma. Then there is no difficulty; the height of the barometer is said to be 29 inches and 3 tenths.

Father. Perhaps, in the course of a few hours, you observe that the mercury has risen a very little, what will you do?

Emma. I will raise the vernier even with the mercury.

Father. And you find the index so much higher than the division 3 on the scale as to bring the figure 1 on the vernier even with the second tenth on the scale.

Emma. Then the whole height is 29 inches 2 tenths, and one of the divisions on the vernier; which is equal to a tenth and a hundredth; that is, the height of the mercury is 29 inches, 3 tenths, and 1 hundredth, or 29.31.

Father. If figure 2 on the vernier stand even with a division on the scale, how should you call the height of the mercury?

Emma. Besides the number of tenths, I must add 2 hundredths, because each division of the vernier contains a tenth and a hundredth: therefore I say the barometer stands at 29.32; that is, 29 inches, 3 tenths, and 2 hundredths.

Father. Here is a representation A B (Plate III, Fig. 28) of the upper part of a barometer tube; the quicksilver stands at between A and C: from *z* to *x* is part of the scale of variation: 1 to 10 is the vernier, equal in length to $\frac{11}{10}$ths of an inch, but divided into 10 equal parts. In the present position of the mercury, the figure 1 on the vernier coincides exactly with 29.5 on the scale: and finding the index stand between the 6th and 7th divisions on the scale, I therefore read the height 29.61: that is, 29 inches, 6 tenths, and 1 hundredth.

Charles. I now understand the principle of the barometer, but I want a guide to teach me how to predict the changes of the weather, which the rising and falling of the mercury presage.

Father. I will give you rules for this purpose in a few days*. Before we meet again, you may commit to your memory some lines beautifully

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* See the end of the volume.

descriptive of this instrument, and which include a just compliment to the memory of Torricelli and Boyle, both of whom are celebrated for their discoveries in this part of science:—

You charm'd, indulgent SYLPHS! their learned toil,
And crown'd with fame your TORRICELL and BOYLE;
Taught with sweet smiles, responsive to their pray'r,
The spring and pressure of the viewless air;
—How up exhausted tubes bright currents flow
Of liquid silver from the lake below:
Weigh the long column of th'incumbent skies,
And with the changeful moment fall and rise.

BOTANICAL GARDEN.

CONVERSATION XX.

Of the Barometer, and its Application to the measuring of Altitudes.

CHARLES. In those lines you gave us to learn, Dr. Darwin says, "Weigh the *long* column of the incumbent skies:" is the height of the atmosphere known?

Father. If the fluid air were similar to water, that is, everywhere of the same density, nothing would be easier than to calculate its height.—When the barometer stands at 30 inches, the specific gravity of the atmosphere is 800 times less than that of water*; but mercury is about 14 times heavier than water, consequently the specific gravity of mercury is to that of air as 800 multiplied by 14 is to 1; or mercury is 11,200 times heavier than air. In the case before us, a column of mercury, 30 inches long, balances the whole weight of the atmosphere; therefore, if the air were equally dense at all heights to the top, its height must be 11,200 times 30 inches; that is, the column of air must be as much longer than that of the mercury, as the former is lighter than the latter. Do you understand me?

Charles. I think I do: 11,200 multiplied by 30 give 336,000 inches, which are equal to $5\frac{1}{2}$ miles nearly.

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* See Conversation VI of this volume.

Father. That would be the height of the atmosphere if it were equally dense in all parts: but it is found that the air, by its elastic quality, expands and contracts, and that at 3½ miles above the surface of the earth it is twice as rare as it is at the surface; that at 7 miles it is 4 times rarer; at 10½ miles it is 8 times rarer; at 14 miles it is 16 times rarer; and so on, according to the following

TABLE.

At the altitude of	3½	miles above the surface of the earth, the air is	-	2	times lighter than at the earth's surface.
	7		-	4	
	10½		-	8	
	14		-	16	
	17½		-	32	
	21		-	64	
	24½		-	128	
	28		-	256	

Now, if you were disposed to carry on the addition on one side, and the multiplication on the other, you would find that, at 500 miles above the surface of the earth, a single cubical inch of such air as we breathe would be so much rarefied as to fill a hollow sphere, equal in diameter to the vast orbit of the planet Saturn.

Emma. Is it inferred from this that the atmosphere does not reach to any very great height?

Father. Certainly; for you have seen that a quart of air at the earth's surface weighs but about 14 or 15 grains; and by carrying on the above table a few steps, you would perceive, that the same quantity, only 49 miles high, would weigh less than the 16 thousandth part of 14 grains; consequently at that height its density must be next to nothing. From experiment and calculation it is generally admitted, that the atmosphere reaches about 45 or 50 miles above the earth's surface.

Charles. By comparing the state of the atmosphere at the bottom and at the top of a mountain, should you perceive a sensible difference?

Father. We must not trust to our feelings on such occasions. The barometer will be a sure guide. I will not trouble you with calculations, but mention two or three facts, with the conclusions to be drawn from them. In ascending the Puy de Domme, a very high mountain in France, the quicksilver fell $3\frac{1}{3}$ inches; and the height of the mountain was found, by measurement, to be 3204 feet. By a similar experiment upon

Snowden, in Wales, the quicksilver was found to have fallen $3\frac{8}{10}$ inches at the height of 3720 feet above the surface of the earth.

From these and many other observations it is inferred, that, in ascending any lofty eminence, the mercury in the barometer will fall $\frac{1}{10}$ of an inch for every 100 feet of perpendicular ascent. This number is not rigidly exact, but sufficiently so for common purposes, and it will be easily remembered. The three following observations were taken by Dr. Nettleton near the town of Halifax: —

Perpendicular altitude in feet.	Lowest station of the Barometer.	Highest station of the Barometer.	Difference.
102	29.78	29.66	0.12
236	39.50	29.23	0.27
507	30.00	29.45	0.55

Emma. If I ascend a high hill, and, taking a barometer with me, find the mercury has fallen $1\frac{1}{2}$ inch, may I not conclude that the hill is 1500 feet perpendicular height?

Father. You may. Are you aware how great a pressure you are continually sustaining?

Emma. No; it never came into my head. I feel no burden from it, therefore it cannot be very great.

Father. You sustain every moment a weight equal to many tons, which, if it were not balanced by the elastic force of the air within the body would crush you to pieces; this is well described by Mr. Lofft.

Internal balancing *external* force,
Remove the external, and, to atoms torn,
Our dissipated limbs would strew the earth;
Remove the internal, in a moment crush'd

By greater weight of the incumbent air,
Than rocks by fabled giants ever thrown.

EUDOSIA.

Charles. We might indeed have inferred that it was considerable from the sensations that we felt when the air was taken from under our hands. But how, Sir, do you make out the assertion?

Father. When the barometer stands at 29.5 the pressure of the air upon every square inch is more than equal to 14 pounds; call it 14 pounds for the sake of even numbers, and the surface of a middle-sized man is 14½ feet; tell me now the weight he sustains.

Charles. I must multiply 14 by the number of square inches in 14½ feet: now there are 144 inches in a square foot; consequently in 14½ feet there are 2088 square inches; therefore 14 pounds multiplied by 2088 will give 29,232 the number of pounds weight pressing upon such a person.

Father. That is equal to about 13 tons; now, if Emma reckons herself half only the size of a grown person, the pressure upon her will be equal to 6½ tons.

Emma. What must the pressure upon the whole earth be?

Father. This you may calculate at your leisure, I will furnish you with the rule.

"Find the diameter of the earth*, from which you will easily get the superficial measure in square inches, and this you must multiply by 14,

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* See Vol. II, Conversation VII, Note, p. 80.

and you get the answer to the question in pounds avoirdupois."

The earth's surface contains about 200,000,000 square miles: and as every square mile contains 27,876,400 square feet, there must be 5,575,280,000,000,000 square feet in the earth's surface, which number multiplied by the pressure on each square foot gives the whole weight of the atmosphere.

Charles. This is truly enormous!

Father. But the pressure being equal, in all possible directions, it has no effect in disturbing either the annual or diurnal motion of the earth.

CONVERSATION XXI.

Of the Thermometer.

FATHER. As the barometer is intended to measure the different degrees of density of the atmosphere, so the thermometer is designed to mark the changes in its temperature, with regard to heat and cold.

Emma. Is there any difference between the thermometer that is attached to the barometer, and that which hangs out of doors?

Father. No; they are both made by the same person, and are intended to show the same effects. But for the purposes of accurate observation, it is usual to have two instruments, one attached to, or near the barometer, and the other out of doors, to which neither the direct nor reflected rays of the sun should ever come. Though my thermometers are both of the same construction, and such as are principally used in this country, yet there are others made of different materials and upon different principles.

Charles. Does not this thermometer consist of mercury enclosed in a glass tube which is fixed to a graduated frame?

Father. That is the construction of Fahrenheit's thermometer: but when these instruments were first invented about 200 years ago, air, water, spirits of wine, and then oil, were made use of: but these have given way to quicksilver, which is considered as the best of all the fluids, being highly susceptible of expansion and contraction, and capable of exhibiting a more extensive scale of heat. Fahrenheit's thermometer is chiefly used in Great Britain, and Reaumur's on the Continent.

Emma. Is not this the principle of the thermometer, that the quicksilver expands by heat and contracts by cold?

Father. It is: place your thumb on the bulb of the thermometer.

Emma. The quicksilver gradually rises.

Father. And it will continue to rise till the mercury and your thumb are of equal heat. Now you have taken away your hand, your perceive the mercury is falling as fast as it rose.

Charles. Will it come down to the same point at which it stood before Emma touched it?

Father. It will, unless, in this short space of time, there has been any change in the surrounding air. Thus the thermometer indicates the temperature of the air, or, in fact, of any body with which it is in contact. Just now it was in contact with your thumb, and it rose in the space of a minute or two from 56° to 62°; had you held it longer on it the mercury would have risen still higher. It is now falling. Plunge it into boiling water*,

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* This should be done very gradually, by holding it some time in the steam, to prevent its breaking by the sudden heat.

and you will find that the mercury rises to 212°. Afterwards you may, when it is cool, place it in ice, in its melting state, and it will fall to 32°.

Emma. Why are these particular numbers pitched on?

Father. You will not perhaps be satisfied if I tell you, that the only reason why 212 was fixed on to mark the heat of boiling water, and 32 that to show the freezing point, was, because it so pleased M. Fahrenheit: this, however, was the case.

Charles. I can easily conceive that at the same degree of cold, water will always begin to freeze; but surely there are different degrees of heat in boiling water, and therefore it should seem strange to have only one number for it.

Father. In an open vessel, boiling water is always of the same heat, that is, provided the density of the atmosphere be the same: and though you increase your fire in a tenfold proportion, yet the water will never be a single degree hotter; for the superabundant heat, communicated to the water, flies off in the form of steam or vapour.

Emma. But suppose you confine the steam.

Father. Before I should attempt this, I must be provided with a strong vessel, or, as you have seen under the article of the steam-engine, it would certainly burst. But in a vessel proper for the purpose, water has been made so hot as to melt solid lead.

Charles. Will you explain the construction of the thermometer?

Father. A B (Plate III, Fig. 29) represents a glass tube, the end A is blown into a bulb, and this, with a part of the tube, is filled with mercury. In good thermometers, the upper part of the tube approaches to a perfect vacuum, and of course the end B is hermetically sealed. If the tube be now placed in pounded ice, the mercury will sink to a certain point x, which must be marked on the tube, and on the scale opposite to this point 32 must be placed, which is called the freezing point. Then let it be immersed in boiling water, the mercury will rise, and, after a few minutes, become stationary. Against that point make another mark, and write on the scale 212 for the heat of boiling water. Between these points let the scale be divided into 180 equal parts.

Emma. Why 180 parts?

Father. Because you begin from 32, and if you subtract that number from 212, the remainder will be 180. Also, below 32, and above 212, set off more divisions on the scale, equal to the others. The scale is finished when you have written against 0 *extreme cold*, against 32 *freezing point*, against 55 *temperate heat*, against 76 *summer heat*, against 98 *blood heat*, against 112 *fever heat*, against 176 *spirits boil*, and against 212 *water boils*.

Emma. You said the scale was to be divided higher than boiling water, but without mentioning the extent.

Father. The utmost extent of the *mercurial* thermometer, both ways, are the points at which quicksilver boils and freezes; beyond these it can be no guide: now the degree of heat at which mercury boils is 600, and it freezes when it is brought down as low as 39° or 40° below 0; consequently the whole extent of the mercurial thermometer is about 640 degrees.

Charles. Is the cold ever so intense as to cause the mercury to sink 40° below the freezing point?

Father. Not in this country; but it is in some parts of Lapland and Siberia; and even here artificial cold may be produced equal to this.

CONVERSATION XXII.

Of the Thermometer.

CHARLES. Is quicksilver, when frozen, a solid metal, like iron and other metals?

Father. It is thus far similar to them, that it is malleable, or will bear hammering. And when quicksilver boils, it goes off in vapour like boiling water, only much slower. Hence it has been inferred, that all bodies in nature are capable of existing either in a *solid*, *fluid*, or *aeriform* state, according to the degree of heat to which they are exposed.

Emma. I understand that water

may be either solid, as ice, or in its fluid *natural* state, or in a state of vapour or steam.

Father. I do not wonder that you call the fluid state of water its natural state, because we are accustomed, in general, to see it so; and when it is frozen to ice, there appears to us, in this country, a violence committed upon nature. But if a person, from the West or East Indies, who had never seen the effects of frost, were to arrive in Great Britain during a severe and long continued one, such as formerly congealed the surface of the Thames, unless he were told to the contrary he would conclude that ice was some mineral, and naturally solid.

Emma. Does it never freeze in the East or West Indies?

Father. It seldom freezes, unless in very elevated situations, within 35 degrees of the equator north and south: it scarcely ever hails in latitudes higher than 60°. In our own climate, and indeed in all others between 35° and 60°, it rarely freezes till the sun's meridian altitude is less than 40 degrees. The coldest part of the 24 hours is generally about an hour before sun rise, and the warmest part of the day is usually between two and four o'clock in the afternoon.

Charles. Are there no degrees of heat higher than that of boiling mercury?

Father. Yes, a great many: brass will not melt till it is heated more than six times hotter than boiling mercury; and to melt cast iron requires a heat more than six times greater than this.

Emma. By what kind of thermometer are these degrees of heat measured?

Father. The ingenious Mr. Wedgewood has invented a thermometer for measuring the degrees of heat up to 32277° of Fahrenheit's scale.

Charles. Can you explain the structure of this thermometer?

Father. All argillaceous bodies, or bodies made of clay, are diminished in bulk by the application of great heat. The diminution commences in a dull red heat, and proceeds regularly as the heat increases till the clay is vitrified, or transformed into a glassy substance. This is the principle of Mr. Wedgewood's thermometer.

Emma. Is vitrification the limit of this thermometer?

Father. Certainly. The construction and application of this instrument are extremely simple, and it marks all the different degrees of ignition, from the red heat, visible only in the dark, to the heat of an air furnace. It consists of two rulers fixed on a plane, a little farther asunder at one end than at the other, leaving a space between them. Small pieces of alum and clay, mixed together, are made just large enough to enter at the wide end: they are then heated in the fire with the body whose heat is to be ascertained. The fire, according to its heat, contracts the earthy body, so that, being applied to the wide end of the gauge, it will slide on towards the narrow end, less or more, according to the degree of heat to which it has been exposed *.

Each degree of Mr. Wedgewood's thermometer answers to 130 degrees of Fahrenheit, and he begins his scale from red heat fully visible in daylight, which he finds to be equal to 1077° of Fahrenheit's scale, if it could be carried so high.

In the next page is a small scale of heat, as it is applicable to a few bodies.

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* We have, in the former parts of this work, observed, that all bodies are expanded by heat. The diminution of the argillaceous substances made use of by Mr. Wedgewood *appears* to be an exception : but as the contraction of these does not commence till they are exposed to a red heat, it may probably be accounted for, from the expulsion of the fluid particles, rather than from any real contraction in the solids.

SCALE OF HEAT.

			Fahrenheit.
Extremity of Wedgewood's scale..........	240°	which answers to	32277°
Cast iron melts.........	at 160		21877
Fine gold melts........	32		5237
Fine silver melts......	28		4717
Brass melts............	21		3807
Red heat visible by day	0		1077
Mercury boils........................			at 600
Lead melts....		*Note.* If these three metals be mixed together by fusion in the proportion of 5, 8, and 3, the mixture will melt in a heat below that of boiling water.	at 540
Bismuth melts			460
Tin melts......			408
Milk boils.........................		at	213
Water boils......................			212
Heat of the human body.......			92 to 97
Water freezes....................			32
Milk freezes....................			30
A mixture of snow and salt sinks the thermometer to			0
Mercury freezes................		at	40°

Charles. You said that Reaumur's thermometer was chiefly used abroad; what is the difference between that and Fahrenheit's?

Father. Reaumur places the freezing point at 0, or zero, and each degree of his thermometer is equal to $2\frac{1}{4}$, or $\frac{9}{4}$ degrees of Fahrenheit's.

Emma. What does he make the heat of boiling water?

Father. Having fixed his freezing point at 0, and making one of his degrees equal to $2\frac{1}{4}$ of Fahrenheit, the heat of boiling water must be 80°.

Charles. Let me see. The number of degrees between the freezing and boiling points on Fahrenheit's thermometer is 180, which, divided by $2\frac{1}{4}$, or 2.25, gives 80 exactly.

Father. You have then a rule by which you may always convert the degrees of Fahrenheit into those of Reaumur: "subtract 32 from the given number, and multiply by the fraction $\frac{4}{9}$." Tell me, Emma, what degree on Reaumur's scale answers to 167° of Fahrenheit.

Emma. Taking 32 from 167 there remains 135, which, multiplied by 4, gives 540, and this, divided by 9, gives 60. So that 60° of Reaumur answers to 167° of Fahrenheit.

Charles. How shall I reverse the operation, and find a number on Fahrenheit's scale that answers to a given one on Reaumur's?

Father. "Multiply the given number by the improper fraction $\frac{9}{4}$, and add 32 to the product." Tell me what number on Fahrenheit's scale answers to 40 on Reaumur's.

Charles. If I multiply 40 by 9, and divide the product by 4, I get 90: to which, if 32 be added, the result is 122: this answers to 40 on Reaumur's scale.

Father. What numbers on Reaumur's scale will answer to 76°, 98°, and 112° of Fahrenheit; that is, to summer heat, blood heat, and fever heat?

Emma. The numbers are $19\frac{1}{2}$, $29\frac{1}{3}$, and $35\frac{1}{2}$ nearly: for

$$76-32\times\tfrac{4}{9}=\frac{176}{9}=19.5.$$

$$98-32\times\tfrac{4}{9}=\frac{264}{9}=29.33,\ \&c.$$

$$112-32\times\tfrac{4}{9}=\frac{320}{9}=35.55,\ \&c.$$

CONVERSATION XXIII.

Of the Pyrometer and Hygrometer.

FATHER. To make our description of philosophical instruments more perfect, I shall to-day show you the construction and uses of the pyrometer and hygrometer, and conclude, to-morrow, with an account of the rain-gauge, and some directions for judging of the weather.

Emma. What do you mean by a pyrometer?

Father. It is a Greek word, and signifies a fire measurer. The pyrometer is a machine for measuring the expansion of solid substances, particularly metals, by heat. This instrument (Plate III, Fig. 30) will render the smallest expansions sensible to the naked eye.

Charles. Is all this apparatus necessary for the purpose?

Father. This, as far as I know, is one of the most simple pyrometers; and, admitting of an easy explanation, I have chosen it in preference to a more complicated instrument, which might be susceptible of greater nicety.

To a flat piece of mahogany, A A, are fixed three studs, B, C, and D, and at B there is an adjusting screw P. H F is an index, turning very easy on the pivot F, and L S is another turning on L, and pointing to the scale M N. R is part of a watch spring fixed at Y, and pressing gently upon the index L S. Here is a bar of iron, at the common temperature of the surrounding air: I lay it in the studs C and D, and adjust the screw P, so that the index L S may point to 0 on the scale.

Charles. The bar cannot expand without moving the index F H, the crooked part of which pressing upon L S, that also will be moved if the bar lengthens.

Father. Try the experiment; friction, you know, produces heat; take the bar out of the nuts, rub it briskly, and then replace it.

Emma. The index L S has moved to that part of the scale which is marked 2: it is now going back. How do you calculate the length of the expansion?

Father. The bar pressed against the index F H at F, and that again presses against L S at z, and hence they both act as levers.

Charles. And they are levers of the third kind, for in one case the fulcrum is at x, the power at F, and the point z to be moved may be considered as the weight:—in the other, L is the fulcrum, the power is applied at z, and the point S is to be moved*.

Father. The distance between the moving point F and H is 20 times greater than that between x and F; the same proportion holds between L S and L z: from this you will get the spaces passed through by the different points.

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* For an account of the different levers, see Vol. I, Conversations XV and XVI.

Emma. Then as much as the iron bar expands, so much will it move the point F, and of course the point *z* will move 20 times as much; so that if the bar lengthen $\frac{1}{10}$th of an inch, the point *z* would move $\frac{20}{10}$ths, or 2 inches. By the same rule the point s will move through a space 20 times as great as the point *z*.

Father. There are two levers then, each of which gains power, or moves over spaces, in the proportion of 20 to 1; consequently, when united, as in the present case, into a compound lever, we multiply 20 into 20, which make 400; and therefore, if the bar lengthen $\frac{1}{10}$th of an inch, the point s must move over 400 times that space, or 40 inches. But suppose it only expands $\frac{1}{400}$th part of an inch, how much will s move?

Charles. One inch.

Father. But every inch may be divided into tenths, and consequently, if the bar lengthen only the $\frac{1}{4000}$th part of an inch, the point s will move through the tenth part of an inch, which is very perceptible. In the present case the point s has moved two inches, therefore the expansion is equal to $\frac{2}{400}$ths, or $\frac{1}{200}$th part of an inch.—An iron bar, three feet long, is about $\frac{1}{70}$th part of an inch longer in summer than in winter.

Charles. I see that, by increasing the number of levers, you might carry the experiment to a much greater degree of nicety.

Father. Well, let us now proceed to the hygrometer, which is an instrument contrived for measuring the different degrees of moisture in the atmosphere.

Emma. I have a weather-house that I bought at the fair, which tells me this; for if the air is very moist, and thereby denotes wet weather, the man comes out; and in fair weather, when the atmosphere is dry, the woman makes her appearance.

Charles. How is the weather-house constructed?

Father. The two images are placed on a kind of lever, which is sustained by catgut; and catgut is very sensible to moisture, twisting and shortening by moisture, and untwisting and lengthening as it becomes dry. On the same principle is constructed another hygrometer. A B (Plate III, Fig. 31) is a catgut string, suspended at A with a little weight B, that carries an index C round a circular scale D E on a horizontal board or table: for, as the catgut becomes moist, it twists itself, and untwists when it approaches to a drier state.

Emma. Then the degrees of moisture are shown by the index, which moves backwards and forwards by the twisting and untwisting of the catgut. Does all string twist with moisture?

Father. Yes. Take a piece of common packthread, and on it suspend a pound weight in a vessel of water, and you will see how soon the two strings are twisted round one another.

Charles. I recollect that the last time the lines for drying the linen were hung out in the garden, they appeared to be much looser in the evening than they were next morning, so that I thought some person had been altering them. A sudden shower of rain has produced the same effect in a striking manner.

Emma. Sometimes, when sudden damp weather has set in, the string of the harp has snapped when no person has been near it.

Father. These are the effects produced by the moisture of the air; the damp of night always shortens hair and hempen lines; and, owing to the changes to which the atmosphere in our climate is liable, the harp, violin, &c., that are set to tune one day, will need some alteration before they can be used the next.

Here is a sensible and very simple hygrometer: it consists of a piece of whipcord, or catgut (Plate III,

Fig. 32), fastened at A, and stretched over several pulleys, B, C, D, E, F; at the end is a little weight W, to which is an index pointing to a graduated scale.

Charles. Then, according to the degree of moisture in the air, the string shortens, or lengthens, and of course the index points higher or lower.

Father. Another kind of hygrometer consists of a piece of sponge E (Plate III, Fig. 33), prepared and nicely balanced on the beam $x\ y$; and the fulcrum z lengthened out into an index pointing to a scale A C.

Emma. Does the sponge imbibe moisture sufficiently to become a good hygrometer?

Father. Sponge of itself will answer the purpose, but it is made much more sensible in the following manner:—

After the sponge is well washed from all impurities and dried again it should be dipped into water, or vinegar, in which sal-ammoniac, salt of tartar, or almost any other saline substance, has been dissolved, and then suffered to dry, when it should be accurately balanced.

Charles. Do the saline particles, in damp weather, imbibe the moisture, and cause the sponge to preponderate?

Father. They do. Instead of sponge, a scale may be hung at E, in which must be put some kind of salt that has an attraction to the watery particles that float in the air. Sulphuric acid may be substituted in the place of salt, but this is not fit for your experiments, because a little spilt over will destroy your clothes, otherwise it makes a very sensible hygrometer.

Emma. I have heard the cook complain of the damp weather when the salt becomes wet by it.

Father. Right: the salt box in the kitchen is not a bad hygrometer.

NOTE.—The ratio of expansion of metallic rods of the same diameter, placed in boiling water, is found to be in brass 94, iron 73, lead 154, and silver 84.

CONVERSATION XXIV.

Of the Rain-Gauge.

CHARLES. Does the rain-gauge measure the quantity of rain that falls?

Father. It shows the height to which the rain would rise on the place where it is fixed, if there were no evaporation, and if none of it were imbibed by the earth. One which is made and sold by Mr. Jones, of Holborn, consists of a funnel A (Plate III, Fig. 34) communicating with a cylindric tube B. The diameter of the funnel is exactly 12 inches, and that of the tube is 4 inches. Tell me, Emma, what proportion the area of the former has to that of the latter.

Emma. I remember that all plane surfaces bear the same proportion to one another that the squares of their diameters have. Now the square of 12 is 144, and the square of 4 is 16, therefore the proportion of the area of the funnel is to that of the tube as 144 to 16.

Father. But 144 may be divided by 16, without leaving a remainder.

Charles. Yes; 9 times 16 is 144, consequently the proportion is as 9 to 1; that is, the area of the funnel is 9 times greater than that of the tube.

Father. If then the water in the tube be raised 9 inches, the depth of rain fallen, will, in the area of the funnel, which is the true gauge, be only one inch.

Emma. Does the little graduated rule mark the rise?

Father. Yes, it does. It is a floating index divided into inches.

Emma. If then the float be raised 1 inch, is the depth of water reckoned only $\frac{1}{9}$th of an inch?

Father. Just so: and each nine inches in length being divided into 100 equal parts, the fall of rain can be readily estimated to the $\frac{1}{900}$th part of an inch. Rain-gauges should be varnished or well painted, and as much water should be first poured in as will raise the float to such a height, that 0, or zero, on the ruler may coincide with the edge of the funnel.

Charles. This is not like your rain-gauge.

Father. That which I use, though somewhat more difficult of explanation, is a much cheaper instrument; it may, without the bottle, be made for a single shilling. It consists of a tin or copper funnel; the area of the top contains exactly 10 square inches, and the tube, about 5 or 7 inches long, passes through a cork that is fixed in a quart bottle.

Emma. Is there any particular proportion between the area of the funnel and that of the bottle?

Father. No, it is not necessary; for in this, the quantity of the rain is calculated by its weight compared with the area of the funnel, which is known. For every ounce of water I allow .173 parts of an inch for the depth of the rain fallen. Thus the last time that I examined the bottle, I found that the water weighed exactly 6 ounces, and 6 multiplied by .173 gives 1.038; that is, the rain fallen in the preceding month was equal to rather more than 1 inch in depth. In the month of June (1801) the rain collected in the gauge weighed $11\frac{1}{2}$ ounces, which is nearly equal to 2 inches in depth.

Charles. Pray explain the reason of multiplying the number of ounces by the decimal .173.

Father. Every gallon of pure rain water contains 231 cubic inches, and weighs 8 lbs. 5 oz. $\frac{2}{3}$ avoirdupois, or 133.66 ounces; consequently, every ounce of water is equal to $231 \div 133.66 = 1.73$ cubic inches; but the area of the funnel is 10 square inches, therefore $1.73 \div 10 = 173$ gives the depth of rain fallen for every cubic inch of water collected, or for every ounce in the gauge.

You have now a pretty full account of all the instruments necessary for judging of the state of the weather, and for comparing, at different seasons, the various changes as they happen.

Emma. Yes; the *barometer* informs us how *dense* the atmosphere is; the *thermometer* enables us to ascertain its heat; the *hygrometer* what degree of *moisture* it contains; and by the *rain-gauge* we learn how much rain falls in a given time.

Father. The rain-gauge must be fixed at some distance from all buildings, which might in any way shelter it from particular driving winds; and the height at which the surface of the funnel is from the ground must be ascertained.

Charles. Does it make any difference in the quantity of rain collected, whether the gauge stands on the ground or some feet above it?

Father. Very considerable: as that which I have described is a cheap instrument, one may be placed on the top of the house, and the other on the garden wall, and you will find the difference much greater than you would imagine.—I will now give you some rules for judging of, and predicting, the state of the weather, which are taken from writers who have paid the most attention to these subjects, and which my own observations have verified.

1. The rising of the mercury presages, in general, fair weather, and

its falling foul weather, as rain, snow, high winds, and storms. When the surface of the mercury is convex, or stands higher in the middle than at the sides, it is a sign the mercury is then in a rising state; but if the surface be concave, or hollow in the middle, it is then sinking.

2. In very hot weather, the falling of the mercury indicates thunder.

3. In winter, the rising presages frost: and in frosty weather, if the mercury falls three or four divisions, there will be a thaw. But in a continued frost, if the mercury rises, it will certainly snow.

4. When wet weather happens soon after the depression of the mercury, expect but little of it; on the contrary, expect but little fair weather, when it proves fair shortly after the mercury has risen

5. In wet weather, when the mercury rises much and high, and so continues for two or three days before the bad weather is entirely over, then a continuance of fair weather may be expected.

6. In fair weather, when the mercury falls much and low, and thus continues for two or three days before the rain comes, then a deal of wet may be expected, and probably high winds.

7. The unsettled motion of the mercury denotes unsettled weather.

8. The words engraved on the scale are not so much to be attended to, as the rising and falling of the mercury: for if it stand at *much rain*, and then rises to changeable, it denotes fair weather, though not to continue so long as if the mercury had risen higher. If the mercury

stands at fair, and falls to changeable, bad weather may be expected.

9. In winter, spring, and autumn, the sudden falling of the mercury, and that for a large space, denotes high winds and storms: but in summer it presages heavy showers, and often thunder. It always sinks lowest of all for great winds, though not accompanied with rain; but it falls more for wind and rain together, than for either of them alone.

10. If, after rain, the wind change into any part of the north, with a clear and dry sky, and the mercury rise, it is a certain sign of fair weather.

11. After very great storms of wind, when the mercury has been low, it commonly rises again very fast. In settled fair weather, except the ba-

rometer sink much, expect but little rain. In a wet season, the smallest depression must be attended to; for when the air is much inclined to showers, a little sinking in the barometer denotes more rain. And in such a season, if it rise suddenly fast and high, fair weather cannot be expected to last more than a day or two.

12. The greatest heights of the mercury are found upon easterly and north easterly winds; and it may often rain or snow, the wind being in these points, while the barometer is in a rising state, the effects of the wind counteracting. But the mercury sinks for wind as well as rain in all other points of the compass.

APPENDIX

TO

VOL. IV.

Of Air, as a Vehicle of Heat and Moisture. Of Rain — Dew — Meteoric Stones.

THE causes which determine the distribution of heat over the earth's surface are, as has been shown in Vol. II, Conversation X, either the direct influence of the solar rays, or the communication of heat by the air, from one part of the earth's surface to another. The first of these depends on the latitude of the place, by which the intensity of the heat and light from the sun, and also the length of the day are determined. But the intensity of the sun's rays, when they strike upon any plane, is as the quantity that falls on a given space; and, of course, the nearer the sun is to the zenith of any place, at a given instant, the greater the intensity of heat produced by his rays.

Moreover, the heat of an entire day depends on the length of the day, as well as on the sun's elevation; and, as the day is longer where the distance from the zenith is greater, the inequality in the distribution of heat, arising from one of these causes, compensates that which proceeds from the other, and brings their combined effects much nearer to an equality than could be imagined.

It has been shown, by M. Fontana, that the heat of the day of the summer solstice at Pavia, in Italy, is scarcely greater than the heat of the same day at Petersburgh; that is, only in the proportion of 63° to 62°, though the latitude of the one is 45° 11′, and that of the other 59° 26′.

The same author finds, that when the sun's declination exceeds 18°, that is, from the beginning of May to the end of July, the heat, in the twenty-four hours, proceeding from the sun's rays, is greater at the north pole than at the equator.

The effects of the direct influence of the sun are greatly modified by the transportation of the temperature of one region into another. Heat expands air, and it thus becomes specifically lighter: but the columns of air, which become lighter by the action of the sun's rays, are displaced by those that are heavier; and hence there is a general tendency in the air to move from the poles towards the equator, which is admirably calculated to moderate the extremes of temperature.

The sea, upon a similar principle, is preserved of a moderate temperature, for the heavier columns of a fluid displace those that are lighter. Hence the waters of the ocean are of a more uniform temperature, which temperature communicates itself to the surrounding air.

The effect of great continents is the

reverse of this, and is favourable to the extremes of heat and cold. High mountains, especially if covered with snow, may increase the rigour of a cold climate, or temper the heat of a warm one.

Forests tend to increase the cold, by preventing the sun's rays from striking on the ground. Evaporation, as is shown in the "Dialogues on Chemistry," produces cold; of course, countries, that abound in marshes and lakes, are subject to an increase of severe cold. And it is an admirable provision of nature, that, in the act of the congelation of water into ice, a great deal of heat is given out, which in some degree moderates the severity of the cold. On the other hand, the melting or thawing of ice produces cold, which prevents the dreadful effects that might be occasioned by a too rapid thaw, especially when the ground is covered with a very deep snow.

The height above the level of the sea causes a diminution of heat at the rate of 1° for about 300 feet of elevation, which agrees with observations made for twelve years at Highgate and Camden Town, the average temperature of the former place being one degree lower than that of the latter.—See Monthly Magazine, vol. xxxvii, p. 231.

The varieties of temperature on the surface of the earth are probably confined between the limits of 100° above and 40° below 0, or zero.

No natural degree of cold much below this has ever been known; and the thermometer, in the shade, has rarely, if ever, been seen at 100°. In this country, as far as can be ascertained, the hottest day was July 14, 1808, when the mercury stood at 93° in an open situation in the neighbourhood of London; but in London, and confined places, it was still higher.

There is no doubt that the climates of Europe were more severe in ancient times than they now are, and the change is ascribed to the better cultivation of the soil. Cultivation may, in fact, improve a climate, first, by draining marshes and low grounds, and thereby lessening the evaporation; secondly, by turning up the soil, and exposing it to the rays of the sun; and, thirdly, by thinning or cutting down forests, which, by their shade, prevent the penetration of the sun's rays. The improvements that are taking place in the climate of North America prove, that the power of man extends to phenomena, which, from the magnitude and variety of their causes, appear beyond its reach.

The vapour that rises from water, uniting itself to the air, ascends into the higher regions of the atmotphere, and is often carried by the winds to great distances. It is chemically dissolved in the air.

Humidity does not lessen, but increases the transparency of the air: hence we often have the clearest atmosphere the day before heavy rains. A cubical foot of air, which weighs about 1¼ ounce, or 600 grains, will, at the temperature of 66°, hold in solution 12 grains, or about the 50th part of its own weight. If two portions of air, of different temperatures, but both saturated with humidity, be mixed together, a precipitation must, on chemical principles, be thrown down in the shape of clouds, or rain.

Dew is a precipitation of humidity from the lower strata of the atmosphere. When air, containing humidity, cools below a certain point, it must begin to deposit its moisture. In this way dew is formed in warm weather, when, on the sun's going down, the heat of the air at the surface is greatly diminished,

Meteoric Stones, which sometimes fall upon the earth, are probably formed from some gaseous substances carried into the atmosphere from volcanoes, &c., and being collected in considerable quantities into one place, may, either by an electric or chemical action, be united into one solid mass. For, if the air contained in a good sized room could, by some chemical union, be brought into the space of a few cubical inches, the substance thus formed would be of a greater specific gravity than any of these meteoric stones: thus, the weight of the air in a room 20 feet long, 12 feet wide, and 10 feet high, is 250 lbs. troy weight; for 20 × 12 × 10 = 2400 cubical feet: but each cubical foot of air weighs 1¼ ounce; therefore, 2400 feet of air will weigh 3000 ounces = 250 lbs.

END OF THE FOURTH VOLUME.

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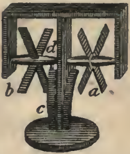
Fig. 2.



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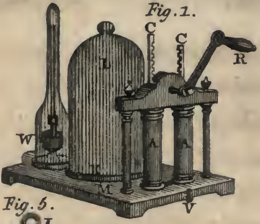

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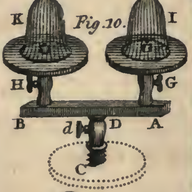

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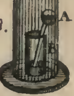

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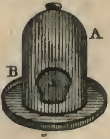
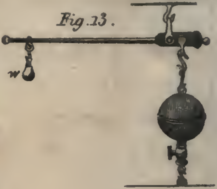


Lowry sculp

Fig. 14.

Fig. 13.



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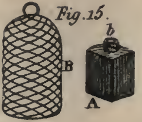

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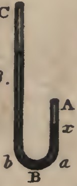

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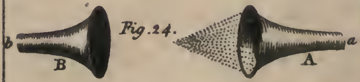

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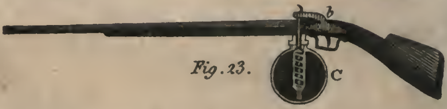

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Fig. 33.

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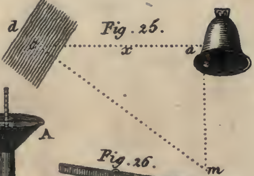

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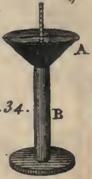

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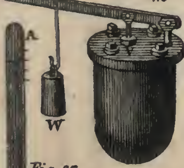

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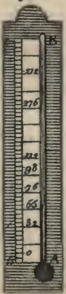

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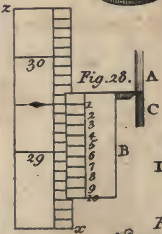

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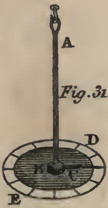

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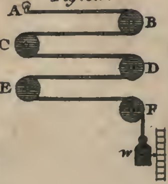

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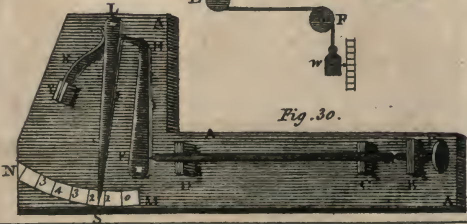

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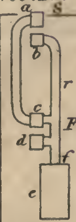
Vol. IV.

Plate 4.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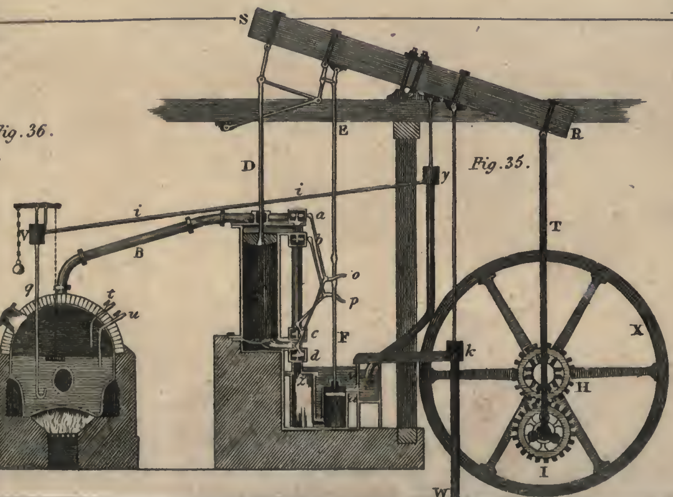
Fig. 35.

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