# What we mean by Force and Pressure

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A POPULAR word is frequently so popular that it is received with open arms, or rather with open mouth and open ears, when really it should not be present at all in the company of those words with which it is associated on that particular occasion to form a sentence.

The scientist, even when talking lightly and brightly (and even flippantly), should be very careful of the words he employs ; so he likes to have all the words he intends to use regularly for scientific purposes carefully defined to have only one meaning.

This article is about what we may popularly term " pushes " and " pulls "—both really quite good words, because we use them so frequently that we know what to expect when we push a thing or pull it. If you simply pull a free object, you expect generally that it will move towards you ; and if you push it, you expect it to move away from you. Scientists prefer to use the word " force " when dealing with this action—we apply a force to a body, and, if the body be free to move, it will move in the direction of the force. So that when we *pull* on a body, we apply a force on it towards ourselves ; when we *push* a body, we apply a *force* on it away from ourselves. We want to know not only how *great* is the *force* we apply, but also the *direction* in which we apply it.

There is a lot more bound up with this idea of *direction* of a force than at first meets the eye. For instance, we may apply a force which would tend to make a body, if *quite* free to move, go in a certain direction, whilst actually it may only be free to move in some other direction ; what is it going to do ?

Everything throughout the universe is moving ; even apart from the movements of a lump of material, the myriads of molecules of which that lump is made are moving in rapid agitation in little tiny paths and " pushing " adjacent molecules as they do so ; and in the case of a gas the molecules are also moving rapidly about throughout the body of the gas. Everything is moving, everything is shoving and pushing and pulling, and the scientist, studying how it happens and why, has to be very careful to discuss it so that everyone else *should* know what he is talking about. We owe quite a lot to Sir Isaac Newton, who lived between 1642 and 1727, for putting into clear statements some of our ideas with regard to forces.

Our world is whirling around on its axis, and also whirling in its orbit round the sun, and the sun and earth and other planets are rushing along in the galaxy of stars, so that we may find it difficult to imagine anything stationary to use as our starting post. Fortunately, we can confine our studies to how things move with respect to one another, so that we can say, " Let's pretend that *this* is fixed, and measure how things move with regard to it ". Most of us are concerned with earthly affairs, so that we can drive a peg into the earth and say, " This peg is stationary, and we will see whether objects move with respect to it ". From *that* point of view anything which does not move relative to the earth is " at rest ". That makes the ordinary surveyor and engine-driver, and even the aeroplane pilot quite happy, and serves quite well for the scientist for much of his work ; but the astronomer would not be satisfied with it. He can say, for some purposes, " Let's consider the sun fixed, and see how the planets and comets move with respect to it ". For other purposes he has to go beyond the sun, and it becomes a very difficult job to select a place that he can conveniently call " at rest ".

For this article we are going to plant our feet firmly on the earth and say that *it* is at rest, disregarding here even the possibility of earthquakes and the earth tidal movements which we know to occur. Newton's first law of motion, in present-day language, is that every body which is at rest will remain at rest unless acted upon by some force outside itself ; and that, if it be moving, it will merely continue to move along a *straight line,* and that without either speeding up or slowing down, unless acted upon by some force outside itself. From this we have a means of knowing whether there is an unbalanced force on a body or not ; if there is a motor-car at rest on a level road, and you have remembered to take the brakes off, you can exert a force on it in, say, the northerly direction in which it points, and it will begin to move ; if you keep on pushing with the same force, the car will go quicker and quicker, or *accelerate.* When the car was at rest, it was not *entirely* free to move ; as soon as you started to push it northwards, resistances due to friction applied an equal force southwards, which just counterbalanced your effort. Then you applied a bigger force than frictional resistances were able to oppose to you, and the body began to move. The *effective* or *resultant* force in this case to push the car is the difference between your northwards push and the southwards push due to friction ; and, even if you only keep on applying the same effective or resultant northwards force, the car accelerates ; if when you got it moving you reduced your applied force to one *just* equal to the existing opposing frictional force, there would be no resultant forward force, and the car would continue with unchanging velocity northwards.

Newton, in his second law of momentum, tells us how this acceleration is related to the effective external force ; if we consider how the velocity of the car is changing from moment to moment, we can measure the time rate of change in the velocity, which is the acceleration; and Newton says, for one thing, that this time rate of velocity change is proportional to the effective moving force in the direction in which we are pushing. This " second law " says more than that, but we must first introduce another term. When we multiply the mass of a body by the velocity with which it is moving, that product is termed its *momentum* ; if our motor car had a mass of 2,800 pounds (which is 25 cwt.), and we pushed it so that at one moment it had a velocity of 3 feet per second (just over 2 miles per hour) northwards, then its momentum would be $2800 \times 3$, which is 8,400 pound feet per second northwards. Newton's second law is that the rate at which the momentum changes in a given direction is proportional to the impressed external force in that direction.

Suppose that you push a thing, and that it does not move at all; then you know that by some means an equal but opposite push is being applied against you. It may be due to the fact that someone else is actually exerting a force in the opposite direction, shoving, or pushing, or exerting a force against you, or it may be that the object is so *fixed* that your push is merely tending to alter the size or shape of the body. Before we can consider this effect, we will have to examine a body to see how it is that it does not always merely go " squash " when we push it, instead of hanging together and transmitting our force from place to place.

Some materials merely *do* squash when we apply small forces to them, even when the area of contact is great; for instance, a policeman holding up his hand to block the passage of the car, and going through the motion of pushing it back, although he is many yards away, merely squashes the air out of the way of his hand without having any *direct* effect on the approach of the inanimate car. The air consists of vast swarms of little particles of gases, the particles being called molecules. They are extremely tiny, and about $4 \times 10^{20}$ (four hundred million million million) of them are in every cubic inch of air under ordinary conditions.

Write down a 4 and then put twenty noughts after it, and you have the number of little molecules wandering round loose in a cubic inch of the air. It is not correct to say that they are " packed " into that space, for although 400 million million million molecules seems a lot to get into a cubic inch, they are so extremely tiny that the gaps between the molecules are great compared with the space occupied by the molecules themselves, so that we can, and do, easily *compress* a gas, that is, squash in 2, 3, 4, or even a hundred or so times, as many molecules into the same space; we " push " all round and through the gas to do this, or, as we say, increase the gas pressure.

These molecules, of oxygen and nitrogen mainly, are buzzing about like bees—darting here and there—as there is really plenty of room between themselves, considering their tiny size, in which they can dart; but they would be fairly rapid bees, because, allowing for their stops when they bump against the walls of the containing vessel and anything else in their way, they have an average velocity of about a thousand miles an hour at ordinary temperatures.

Let us now fix in our minds a little jar containing a cubic inch of air, just like the air outside the jar; in this jar swarm 400 million million million molecules, so tiny that there is plenty of room for them to dash about, and they do so at an average velocity of a thousand miles an hour. We can go back to our earlier ideas on Newton's laws and link this up. To start a thing moving, or to increase its velocity, you have to apply a force in the direction in which you want to increase the velocity; conversely, if you want to slow the object down, or stop it, you have to apply a force in a direction opposite to that in which it is moving; and the more rapidly you wish to change its velocity, then the greater the force you must apply. Consider, for instance, that you dive from a height of ten feet into water; the molecules of water offer little resistance to cutting apart, so that if you give them the opportunity of getting out of the road as you enter gracefully with outstretched hands and arms, it takes a relatively long time to stop you, hence the force opposed to you is relatively small; but if you make the error of falling flat on the water from the height of ten feet, you try and force a big body of water down and out of the way, and so are stopped *quickly* ; thus a big force opposes you, with painful consequences. Supposing you fall from the height of ten feet on to concrete, your body will act partially as a pad to pull you up, because the concrete refuses to get out of the way. If you happen to be well padded, then the yielding of your cushioney cover will take a little time, so that the stop is not so sudden, and hence the opposing force is not so great as if you were stopped more quickly. Thus, when an object falls from a height and strikes the water or the ground, it is no use asking us "with what force does it strike?" We would want to know not only its striking velocity (or from what height it fell) and its mass, but also how long was occupied in bringing it to rest on striking.

Returning to our cubic inch of air, in which we left the 400 million million million molecules darting about frantically. Naturally, swarms of them are going to strike the walls of the containing vessel every second, be brought temporarily to rest, and then bounce off in the reflected direction again. Every one of these smashes against the side of the vessel must exert a force on it, just as a motor car smashing into a wall exerts a force on it. So that a force is exerted all over the inside of the vessel, due to the molecules hitting it ; this force on a wall of a vessel, divided by the area of that wall, we term the pressure exerted by the gas. Pressure is the force per unit area. Outside the vessel we have the atmosphere, and unless we have squashed an extra number of molecules into our enclosed cubic inch, or increased their speed (by heating the contained air), these outside molecules will be just as numerous and travelling with the same average speed ; so they force a wall of the vessel in one direction, and the inside molecules try and kick it in the opposite direction with the same force, and so it does not move.

We are walking about in the air, and are subjected all the time to this machine-gun bombardment of molecules ; vast numbers of the tiny things, travelling with high velocity, smashing up against us every second.

A unit of force with which every one is familiar is the weight of a pound—the opposition force which one has to exert to prevent a pound of material being pulled to the earth. The molecules which bombard us exert a force of nearly fifteen pounds weight over every square inch of our bodies, due to their using us as bouncing boards. As pressure is force per unit area, we say that we are in an atmosphere which exerts a pressure of fifteen pounds weight per square inch, or that we are subjected to an air pressure of fifteen pounds weight per square inch. We are accustomed to that, and all the fluids and gases in our bodies are at the same (or greater) pressures, so that we are merely squashed a bit, but do not collapse ; but if we go suddenly into a vessel in which there are many less molecules per cubic inch (that is, a place in which the pressure has been reduced), then we tend to be burst by the excessive internal pressure, and frequently do burst blood vessels. The higher we go in the air the fewer the molecules per cubic inch, and so the less the pressure. For this reason aviators frequently become unconscious through climbing too rapidly to high altitudes ; we must give time for the gases dissolved in the blood at previous high pressures to readjust themselves.

We can appreciate now that a force must be exerted to cause a body to move, or to change its velocity in any way. The pull of the earth on a pound lump of material is a force, which would tend to make it go faster and faster if free to fall: it would cause the body to increase its velocity at the constant rate of thirty-two feet per second every second (32 ft. per sec. per sec.); if we want to keep the body from moving, then we have to apply an equal force in the opposite direction—that is what we mean by a weight of one pound. We also know now what we mean by pressure; for many purposes we may wish to exert a big force, but not unduly to squash the molecules to which we apply it, so we spread our force over a big area—pressure is *not* force, it is force divided by the area over which it is applied; when you sit on a chair, you do not fall to the ground, because the molecules of the chair, acting all over the area of contact, bombard you upwards with a force equal to your weight downwards, so that your resultant force is nothing, and you stay at rest; if you sit on a drawing-pin, point up on the chair, you are trying to exert the same force over a much smaller area, that is the pressure has now become very great—greater than the molecules of you over that area mutually can withstand—and they are pushed apart as the pin point penetrates.

Do not muddle force and pressure—theyrepresent quite different ideas; and try as soon as possible to get clear ideas as to forces and their effects, learning also the units and how to employ them, if you are making a study of science in any branch.

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## A VISITING SCIENTIST.

Arrangements have been made for a public lecture to be delivered by Dr. H. S. W. Massey (Independent Lecturer in Mathematical Physics, Queen's University, Belfast) in the Physics School, The University of Sydney, at 8 p.m. on Thursday, August 26. His subject will be " The Modern Study of the Atom ". Dr. Massey is an Australian, and one of Melbourne's most distinguished graduates; he is the joint author (with Mott) of the monograph on " The Theory of Atomic Collisions " in the series of " International Monographs in Physics " (Oxford University Press).

Dr. Massey is visiting Australia by arrangements with the Australian Broadcasting Commission; he may be heard on the national network at 5 p.m. on Sunday, August 15, and at 7 p.m. on Monday, August 23. He is at present lecturing in Melbourne for the University Extension Board.

A charge of two shillings will be made for attendance at the lecture, payment being made on admission.

This lecture should be of particular interest to teachers of physics or chemistry.