Some useful fictions

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The object of this article is not to encourage scepticism but rather to combat it by attempting to distinguish between concepts which correctly express physical reality and those deliberate fictions which aid visualization or simplify calculations. At the outset a distinction needs to be made between idealizations, models and fictions. An idealized object, such as a perfect gas or a perfectly smooth wall, is not found in the observed world but it is not a contradiction of it either; it might be regarded as a higher limit to empirical realization. A model, such as the Bohr atom or the drop-model of the nucleus, is of uncertain representative value yet it is retained as a useful tool in discovery. A fiction, such as a magnetic pole or centrifugal force, is a deliberate falsification of reality which has been found useful. It is this very usefulness which is the criterion whether it should be retained or not. Fictions are rather dangerous guests in physics in that a constant vigilance is required to remember their fictitious character, a vigilance that is all too easy to lose. If these convenient myths are tacitly presented to the intelligent student as real it can cause him to unconsciously abandon the effort to make physics intelligible and coherent beyond a certain point. The present writer does not subscribe to the view that the *whole* qualitative content of physics is merely a useful mental construct or model without any necessary reference to reality.

A selection, by no means exhaustive, is given of some fictions which are employed in sixth form physics and each is followed by a brief analysis. It is hoped that this may contribute to the constant battle to make physics ever more clear and comprehensible.

The point particle The fiction of a particle whose mass is concentrated at a mathematical point is used in particle statics and kinetics since it allows us to ignore torques and rotations and to concentrate on translations only. However the translational effects of forces on a body are the same whether the forces meet at a point or not (Atkin 1956) and it would have the virtue of realism if a particle were re-interpreted to mean a body so small that its rotations were imperceptible and could be ignored, therefore allowing us to attend to translational motions only. As well as being more realistic and less strenuous to visualize, this approach permits a more rational transition to perceptibly extended bodies since from the outset it has been maintained that the same translational laws apply to bodies of all sizes.

Resultant of a number of forces The resultant of a number of forces acting on a body is a single equipollent force; that is, if it acted alone on the body it would exercise the same action as the given combination does. When the several concurrent forces are replaced in thought, representation and calculation by the resultant, then the latter becomes a convenient fiction. The concept of the resultant force is certainly useful. However it needs to be remembered that in reality the original forces do not lose their separate identities nor are they sort of blended into a single resultant.

Components of a force Any force can be resolved into components acting along prechosen lines. These components if applied simultaneously to the body would exercise the same action on it as the original force does. When the actual force is replaced in concept and calculation by a pair of equipollent components the latter become useful fictions. This contrivance is used very conveniently in friction where the actual reactive thrust is 'replaced' by the normal reaction and the tangential reaction (ie the friction). Often it is not realized that the latter components do not really exist as independent forces.

Forces acting along a single line No force is actually concentrated along a mathematical line or applied to a mathematical point. For example weight is usually conceived as acting along a line passing through the centre of gravity. In reality the weight of a body is the totality of the separate pulls of gravity acting on the very many individual particles composing the body. What is usually thought of as the weight is the (fictitious) resultant of all of these. Similarly the reactive thrust of a surface on the body it supports is the totality of the local thrusts at the many high-spots in contact. Conceived as a single reaction acting through a definite point it becomes a useful fiction.

Centrifugal force This is one of the classic fictions. There seems to be general agreement that it should no longer be treated as 'useful' since it almost inevitably confuses (Warren 1971).

Circular motion 'associated' with simple harmonic motion This is a useful contrivance for deriving the equations of SHM in a noncalculus treatment of the subject. Students are very prone to attribute some sort of reality to this 'myth' or fthey hopelessly confuse it with SHM and its fictitious nature needs to be stressed from the outset. It might help here also if the final equations did not contain the angular velocity explicitly but rather only the observables of the motion; that is, the frequency, amplitude and acceleration constant.

Potential energy This is not, of course, a mere contrivance, however, as normally understood the concept of potential energy seems to be partly fictitious in character: when a stone is projected upwards its kinetic energy gradually disappears to be stored somehow in the 'geometry of the system'. What happens in fact is that when the stone is projected upwards it gradually loses kinetic energy to the *mass* of the earth. This relativistic mass is potential energy for the stone in that it is immediately available to be returned to it should it drop back again. Similarly the binding energy of an atom is the mass–energy lost by the nucleus (mainly) in drawing the electrons into orbit; the mass of a stretched spring is greater than that of an unstretched spring; a charged rod loses mass when it induces charges in an insulated conductor. These changes in mass may be quantitatively insignificant but they are of first importance in explaining physics.

Lines of force in electrostatic and magnetic fields These are an aid to visualizing not the field itself but the pattern of intensities and directions in the field. Need it be repeated that they are a mapping and do not really exist? However as there is no other way of visualizing the field there is a need to objectify the lines; that is, to attribute them to the field in thought. A certain mental agility is required to employ lines of force and at the same time keep their fictitious character consciously in mind. But this must be done if physics is to be presented as meaningful and taught with consistency.

The magnetic induction B The formal mathematical structure of the magnetic field is partly fictitious in that it attributes a direction and independence to the field not possessed by it in reality. From relativity (Smythe 1950) it is known that the magnetic field is a relativistically 'perturbed' electric field and that the true direction of the magnetic field is simply the direction of the force on a current element placed in it and is not at right angles to that force. However the traditional presentation of current-magnetism is indispensible in that it allows a separation of the magnetic field and the current it acts upon. Indeed it is most difficult to imagine any other way of presenting magnetism. But is it not symptomatic of contemporary physics that the magnetic field is given equal status with the electric field?

Magnetic poles These are doubly fictitious in that they are contrivances employed to allow a simplified calculation of the magnetic field of magnets, whose formal mathematical structure is itself partly fictitious. It is remarkable that some writers (Wick 1969) still speculate about whether they might exist! It seems to the present writer that a clear consequence of special relativity is that the magnetic field is a special electric field produced directly by electrons in motion. The very economy of nature forbids the existence of poles. They should be retained for teaching purposes however for they simplify many explanations enormously and can be used as a sort of classical example of really useful fictions!

Conventional sense of the electric current When electric fields are applied to electrolytes and plasmas the charge carriers, being both positive and negative, are driven both along and against the field.

In metals the charge carriers move opposite the direction of the field. Furthermore all of these currents are directed drifts superimposed on random thermal motion. Quantum theory adds a further complication to the situation. The microscopic picture of electric currents is very complex indeed. However the possibility of constructing useful fictions comes to our aid. For the convenience of macroscopic visualization the current is conceived as a fine-grained steady flow of positive charges driven against electrical resistance by an applied electric field, in the direction of the field. Many effects are the same whether positive charges flow with the field or negative charges flow against it or both flows occur together. For general current theory this is perfectly adequate. For special cases however a more accurate picture must be used. Clearly no particular choice of current direction would have been satisfactory since in general the electric current is a 'two fluid' system. But surely it was a happy accident which gave us a positive nucleus!

Conclusion

If fictions are to be employed in physics and it seems that they must be, then they should be explained for what they are and taught plainly as fictions. They abound in physics. One could go on to consider rays of light, Coriolis force, electromotive force, RMS current and others, and indeed there certainly seems to be far too many of them in advanced physics. As soon as a fiction is recognized as no longer useful or even as positively harmful the insight should be disseminated more rapidly than occurs at present. How long has it taken for us to abandon centrifugal force!

References

Atkin R H 1956 *Mathematics and Wave Mechanics* (London: Heinemann) pp 137–8

Warren J W 1971 *Physics Education* **6** 74–7

Smythe W R 1950 *Static and Dynamic Electricity* (New York: McGraw-Hill) pp 565–6

Wick G L 1969 *New Scientist* **43** 526–7

Queries in physics

Q238 (*from QIP*26) see *Physics Education* 7 452 (How and why is a sound wave reflected from the *open* end of a tube?)

A238 (*from QIP*27)
K W Lyon writes: It can be pointed out that the speed of sound in a tube differs from its speed in free air and an analogy with the reflection of light at the boundary between two media should make the effect intelligible. Presumably if the diameter increases there comes a time when the air would be 'free' and the effect would disappear.
(QIP Editor's note: The exponential 'horn' of directional loudspeakers presumably minimizes the reflected wave down to a certain frequency.)
W K Mace writes: A sound wave consists of displacements of the air, but also, therefore, of pressure changes. A region of compression travelling along a tube is constrained by the walls of the tube, and can only be 'released' by the movement of air which is itself able to move only axially. However, when a region of compression reaches the open end, expansion can take place in all directions into the open space outside. From the point of view of the compression, this represents a sudden reduction in the effective 'inertia' of the air in front of it, and the result is an 'overshoot', the compression turning into a region of low pressure. This region is being 'released' from in front excessively, and becomes 'filled' from behind. This is the beginning of the reflected rarefaction. A set of dynamics trolleys linked by Nuffield A compression springs illustrates this very well.

As regards diameter, my theory is not up to a definite answer, but I would think that reflection would begin to fall off in efficiency as the diameter approaches the value of the wavelength (similar comments were received from O B Keyes).

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