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A trial of two energies

One controversy above all others appears to have occupied the minds of physics teachers writing for this journal during the last 20 years. 'It was the best of times, it was the worst of times, it was the age of wisdom, it was the age of foolishness…it was the season of Light, it was the season of Darkness…' [1] – the era when Nuffield-inspired imaginative physics teaching also led to what has been described as the 'kinetic energy debacle'. This letter sets out what I believe to be the most appropriate approach to teaching about energy to pupils aged 11–16.

In 1966, as part of a widely acclaimed and much needed reform of secondary science teaching, the Nuffield Foundation published its *Teachers' Guide I* [2], together with companion volumes for students that set out the new Nuffield O-level physics course for 14–16-year-olds.

In traditional texts of the time, energy is mentioned very little. For example, Smith [3] defines energy as the capacity of a body for doing work and from this explains the concepts of kinetic and potential energy; surface energy (of a liquid) is explained as an example of potential energy; Tyler [4] refers to heat as a form of energy and uses the expression 'internal energy'.

There are very few energy references in these books that include mechanics and the properties of materials. In textbooks on electrical theory [5] it is clear that writers are content when energy is defined solely in terms of work, kinetic energy, potential energy, internal energy and heat.

The term 'electrical energy' is introduced in *Physics: A Basic Science* [6], but it is clear that it refers to energy that is delivered in the form of heat by an electrical circuit. Abbott [7] (a leading O-level textbook of the period) discusses 'Work, energy and power' in terms of work, kinetic energy and potential energy, internal energy and heat. Kinetic and potential energy are 'Mechanical energy', and 'Nuclear energy' is mentioned only as a section heading.

The Nuffield Guide emphasizes the universal occurrence of energy by giving it different labels according to where it is perceived to be (e.g. spring energy, electrical energy, mechanical energy, chemical energy, atomic energy, breakfast energy). Everyday words (uphill energy, motion energy) were introduced as substitutes for established terms, but new words were coming from two different sources: alongside the introduction of the Nuffield approach the 'energy crisis' led to an emphasis on energy conservation as an environmental priority. Different sources of energy were given different names (e.g. nuclear energy, wave energy, tidal energy, hydroelectric energy and geothermal energy). There was bound to be confusion between the requirement for energy conservation (saving fuel) and the entirely separate established concept of the conservation of energy. Both Dennis Chisholm [8] and I [9] drew attention to this proliferation of different words for energy as, increasingly by the late 1980s, no distinction was being made between these words and the four established terms for physical types of energy, which were noted above.

If the various terms had been used, as the writers of the *Nuffield Guide* intended, simply for introductory discussions, no harm would have been done. The serious problem arose when these started to find their way into tests and examinations. As soon as people started asking examination questions about what sort of energy was to be found at various points in different physical systems, it became necessary to give unique answers to these questions. In some cases there are, in fact, several correct answers; in others none: 'energy labelling' nevertheless became a disease of elementary physics tests and examinations. Many pupils and teachers enjoy such an apparently simple and straightforward procedure, but that is not a good excuse for adopting it.

For example, questions are often asked about the energy changes in steam-driven and hydroelectric power stations. It is clear that the answers expected for the steam-driven system are: chemical energy (of the fuel); heat energy (of the steam); kinetic energy (of the moving parts); electrical energy (in the wires); and heat and light energy (in the lamp). The answer relies entirely on descriptive terms for energy and ignores the role of work, so it cannot be reconciled with the more conventional ideas about energy and work.

Many teachers adopt the more conventional approach with their AS- and A-level classes (ages 16–18) but use an energy-labelling approach with more junior classes. Imagine what might happen if a teacher gave a GCSE class a (descriptive) lesson on energy, using a steam-driven generator, which was then left out on the front bench. In the following lesson some A-level students ask their teacher to explain the steam-driven generator:

Student: 'How does the generator set work?'

Teacher: 'The pressure of the steam acts on the piston, which turns the shaft. This is linked to the dynamo, and the motion produces an electromotive force in the generator coils. The resulting flow of current through the dynamo and lamp causes electromagnetic induction in the dynamo rotor, opposing the force of the steam on the piston. This allows the steam pressure to do work against the resistance of the filament, thus lighting the lamp.'

Student (remembering what had been taught in the GCSE course): 'What about the energy?'

Teacher: 'The energy transferred from the steam, apart from some losses along the way, appears in the filament, causing electromagnetic radiation and heat to be produced.'

The most serious discrepancy in the descriptive approach is describing the moving parts as transmitting kinetic energy. It would be much more accurate to say that the shaft is transmitting forces, which are moving the positions of their points of application: a straightforward example of work. In addition, just as a mechanical linkage can be seen to be allowing one part of a system to do work on another, the same can be said for linkage by an electrical circuit, such as that linking the dynamo and lamp. The term 'electrical energy' has no physical meaning, but it might customarily be found applying in general terms to energy that has been delivered by a circuit.

The student who asked the question is likely to remain confused. Talking only about 'energy' and ignoring (for the sake of simplification) the concept of work, the simplifiers have lost the plot. It is much better, Feynman points out (box 1), to forget about energy and to concentrate on describing what is actually happening in any physical system.

It is clear that energy and work form a duality. A *system* can be said to possess energy [10], and when energy is transferred, work is done. A true description of what goes on in any transfer of energy inevitably involves both concepts.

Many mistakes are made in teaching kinetic and potential energy. It is important to realize that a body, taken in isolation,

1. Feynman's views on 'energy'

Richard Feynman was once asked to review some school textbooks:

'For example, there was a book that started out with four pictures: first there was a wind-up toy; then there was an automobile; then there was a boy riding a bicycle; then there was something else. And underneath each picture it said: "What makes it go?"

'I thought: "I know what it is: They're going to talk about mechanics, how the springs work inside the toy; about chemistry, how the engine of the automobile works; and biology, about how the muscles work."

'I turned the page. The answer was, for the wind-up toy: "Energy makes it go." And for the boy on the bicycle: "Energy makes it go." For everything: "*Energy* makes it go."

'Now that doesn't *mean* anything. Suppose it's "Wakalixes". That's the general principle: "Wakalixes makes it go." There's no knowledge coming in. The child doesn't learn anything: it's just a word!

'What they should have done is to look at the wind-up toy, see that there are springs inside, learn about wheels and never mind "energy". Later on, when the children know something about how the toy actually works, they can discuss the general principles of energy.

'It's also not even true that "energy makes it go". Because if it stops, you could say "energy makes it stop" just as well. What they're talking about is concentrated energy being transformed into more diluted forms, which is a very subtle aspect of energy. Energy is neither increased nor decreased in these examples: it's just changed from one form to another. And when the things stop, the energy is changed into heat, into general chaos.'

Feynman R P 1992 *Surely You're Joking, Mr Feynman* (London: Vinage)

2. Other views on 'energy'

'Heat is not a thing. We can have hot things and cold things, but we cannot take the heat out and away from the thing, and keep it separately in a bottle.'
Andrade E N daC and Huxley J 1932 *Things Around Us* (Oxford: Basil Blackwell)

'Electricity…is not a thing like St Paul's Cathedral; it is a way in which things behave.'
Sir Lawrence Bragg (quoting from Bertrand Russell) 1934 Royal Institution's Christmas Lectures 'adapted to a juvenile auditory'; Bragg L 1936 *Electricity* (London: G Bell and Sons)

'We must be careful not to build up for energy a reputation as a magic word that will answer any question about why things happen.'
Nuffield Physics Teachers' Guide I 1966 (London: Longmans/ Penguin)

'Heat is work and work is heat.
Heat cannot of itself pass from one body to a hotter body:
Heat won't pass from a cooler to a hotter –
You can try it if you like but you far better notter,
'Cause the cold in the cooler will get hotter as a rule-r
Because the hotter body's heat will pass to the cooler…
Heat is work, and work's a curse,
And all the heat in the Universe
Is gonna cool down, because it can't increase
Then there'll be no more work, and there'll be perfect peace –
That's entropy, man…'
Michael Flanders and Donald Swann, from their song 'First and Second Law', performed in their show *At the Drop of Another Hat*, recorded at the Theatre Royal, Haymarket, London, 1964

cannot be said to possess any kinetic energy. There has to be an observer to complete the system, and the speed that matters is the relative speed of the body and the observer. Thus we must visualize kinetic energy as belonging to a system in which it is contained, and from which it can be transferred, and we might therefore see it as just one more example of what has traditionally been called potential energy.

Work is a 'stand alone' concept, whereas energy can be legitimately qualified as kinetic, internal, elastic, surface, electrostatic, gravitational, etc. These terms describe the nature of the system storing the energy, not merely its location. If we do not need to make any special distinction between kinetic energy and the other forms, it might make it easier for us to conceptualize the relationship between work and energy.

All energy is potential work. It could be argued that the expression 'potential energy' is a tautology and that we should simply be talking about work and energy. Energy cannot be thought of as an invisible fluid [16]. It is a difficult quantity to pin down descriptively (box 2), but it is easy to do so mathematically.

References

[1] Dickens C 1859 *A Tale of Two Cities* (London: Chapman and Hall)
[2] *Nuffield Physics Teachers' Guide I* 1966 (London: Longmans/Penguin)
[3] Smith C J 1953 *The General Properties of Matter* (London: Edward Arnold)
[4] Tyler F 1965 *Heat and Thermodynamics* (London: Edward Arnold)
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[6] Verweibe F L, Van Hooft G E and Suchy R R 1962 *Physics: a Basic Science* 4th edn (Princeton: Van Nostrand)
[7] Abbott A F 1969 *Ordinary Level Physics* 2nd edn (London: Heinemann)
[8] Chisholm D 1992 Some energetic thoughts *Phys. Educ.* **27** 215–20
[9] McIldowie E 1995 Energy transfer: where did we go wrong? *Phys. Educ.* **30** 228–30
[10] McClelland G 1989 Energy in school science *Phys. Educ.* **24** 162–4

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How do wings work? A few more thoughts

I read Holger Babinsky's article in November's *Physics Education* with delight, thanks to his clear analysis of how wing lift operates.

His comparison of the effects of wing curvature for a thin and thick aerofoil was particularly worth noting. However, back on p486, Ken Zetie seemed to suggest that there should be some net deflection of the airstreams downwards – rather like that producing the lift on an angled kite – and berated the admittedly rather oversimplified diagram included. Yet on p497, in Holger's first smoke streamline photograph, there is little or no overall deflection of the airstream that Ken Zetie demands.

There is, of course, an overall centripetal force downwards of the air, which is caused by the wing shape, so as the aerofoil has caused a net downwards force of the air, the other half of the Third Law pair is the net upwards force of the air on the wing.

Richard Field

Follow-up: How do wings work?

In the first of our articles (p486) KZ suggested that there must be a net deflection of the air downwards. However, it was pointed out that the pictures in the article by HB (p497) don't show this.

Our first response is that a close look at the picture on p497 does show such a deflection between the incoming and the departing streamlines. However, we also accept that a slight simplification could lead to an inaccuracy here, so we thought it would be best to amplify the basic ideas that are put forward in the shorter article.

The gist of the argument was that for there to be lift on a wing there must be a continuous force on the air. That will result in an acceleration of the air and hence a change of direction. This is true as long as no other forces act on the air. If a very large box is drawn round the wing then you would see streamlines entering and leaving the box horizontally. This is the result of additional forces from the surrounding air (whose pressure changes) and the ground on the air (as the Earth is ultimately pushed down). If a box is drawn so that it just encloses the wing, the streamlines will show a deflection because there will be a pressure gradient in the immediately surrounding air. For the size of box typically drawn in streamline pictures this deflection is apparent, hence the statement made in the earlier article. Essentially this boils down to the difficulty of drawing a free-body diagram in a fluid. There are external forces on the system that may not be evident, due to pressure gradients, and the amount of force will depend on the size of box considered. Then boundary conditions need to be considered – at a very large distance the pressure is atmospheric and streamlines return to being horizontal. However, Newton's Laws still apply so long as one considers all of the forces acting. The idea of drawing a small box is to reduce the effect of those external forces.

To remain on safe ground here it is still true to say that the change in momentum of the air is an indication of lift on the wing. It does not necessarily follow that the momentum change only occurs in one place – indeed, the deflection of the air is quite complex, being deflected up before the wing, down over it and up again afterwards.

We hope this helps to answer the question raised.

Ken Zetie and **Holger Babinsky**