CHAPTER 09

Work and Energy

RUNNING OUT OF ENERGY 9.1

If you leave a torch turned on, its batteries will run out of energy. But has the energy gone forever? Where did it go? These are fundamental questions when it comes to energy. As you probably learnt in earlier science studies, energy is not lost — it just gets transferred from one place to another. This is called the **law of conservation of energy**. The universe seems to have a finite amount of energy that is continually being rearranged.

Think about these questions:

- If you stand still, you are using up energy, but where does it go?
- Why can't a ship extract heat from sea water to power its engines?
- Will there really be an energy crisis soon? Are we running out of energy?

NOVEL CHALLENGE

Why do you lean forward when you get up out of a chair?

NOVEL CHALLENGE

When bodies interact, the energy of one may increase at the expense of another. But we can't intercept the energy and bottle it. So comment on this assertion: 'Energy is not a thing; it is a property of a body.'

NEI Activity 9.1 ENERGY AT HOME

To help you become more familiar with the energy, work and power terms, find out the following:

1. *Electric kettle* If you have an electric kettle, look underneath for its rate of energy consumption, which will be expressed in watts (W). For example, the Kambrook Flash has 2000 W stamped on it. Did anyone in the class get below 1600 W or over 2400 W? Why couldn't the manufacturers make a 20 000 W kettle? It would boil water in a flash!
2. *Food energy* Most foods have their energy content written on the label. A 'Popper' apple juice carton states that the energy is 206 kJ per 100 g. But it also expresses it another way. Look at a food container from your cupboard and note the two ways that energy content is expressed.
3. *Engine power* If your family owns a car, truck or motorbike and you can find the owner's manual, find out the power output of the engine. For example, a GXL Turbo Land Cruiser has a power output of 118 kW. But following this number is a further specification to do with the power. What is it?

ENERGY AT WORK 9.2

A simple definition of energy is that **energy is the capacity to do work.** The word 'energy' stems from the Greek *en* meaning 'in', and *ergos* meaning 'work'. But this doesn't really give us a good understanding of the idea of energy and work. Physicists didn't develop a good understanding of these concepts until 100 years after Newton's death. Today these ideas are considered fundamental to the processes of nature.

Energy transfers

The above definition indicates that energy can be converted into useful work; for example, when the electrical energy in a car's battery is used to start the engine. The reverse is also true — work can be converted into stored energy. For example, we can do work to pump water from a lake to a high reservoir. That stored water has higher energy because of its height and can later be used to drive electric generators and produce electrical energy. When energy is transferred *to* an object we say work is done *on* the object; when energy is transferred *away from* an object we say that work is done *by* the object:

- Energy transferred *to* an object (work done *on* the object): e.g. water pumped up to a reservoir.
- Energy transferred *away from* an object (work done *by* the object): e.g. water flows back down.

Energy losses in transfer

When a torch is turned on, some of the energy stored in the chemical bonds is transferred to the electric charge that flows through the bulb. Some of this energy is transferred into light and some as heat energy to the glass bulb and air.

Energy transfers never achieve 100% **efficiency**, that is, some of the energy is transferred to places you don't intend it to go to. For instance, the energy from the torch that goes to heating up the glass and air is wasted — it is a loss in the sense that it didn't get turned into light. But it is not really lost; energy never is. It just goes to the wrong place. **Efficiency is a measure of the useful energy output compared with the energy input.**

$$\%\ \text{efficiency} = \frac{\text{energy out}}{\text{energy in}} \times 100\%$$

Some energy transfers are listed in Table 9.1.

NOVEL CHALLENGE

In 1916, a Dr Taylor observed a man carrying 40 kg 'pigs' of iron 11 m up a 2.4 m high incline to a train carriage. He carried 1156 pigs in 10 hours. The man's mass was 65 kg and he rested for 15% of the time.
What was his average power output for the $8\frac{1}{2}$ hours?
On a later occasion and without a rest he could only carry 305 pigs in the 10 hours. By what factor was his power output increased when he had proper rest? Suggest why cyclists use a sprint–coast–sprint sequence.

Table 9.1 ENERGY TRANSFERS AND LOSSES

DEVICE	USEFUL ENERGY TRANSFER (ENERGY IS CONVERTED TO USEFUL WORK)	% OF TOTAL ENERGY TRANSFERRED THAT IS USEFUL (% EFFICIENCY)	NON-USEFUL ENERGY TRANSFERS (ENERGY IS NOT CONVERTED TO USEFUL WORK)
Petrol engine	chemical → mechanical	25	heat, sound
Electric light	electrical → light	5	heat
Fluorescent light	electrical → light	20	non-visible radiation
Solar cell	light → electrical	21	heat; re-emission of light
Battery	chemical → electrical	85	heat
Electric motor	electrical → mechanical	90	heat

INVESTIGATING

What energy transfer occurs for humans? What percentage of the input energy is transferred to non-useful purposes?

Forms of energy

The jumble of terms like light, heat, electricity, sound, mechanical and chemical doesn't provide a systematic way of organising the different forms of energy. Before we can go any further, we need a way of classifying energy.

Bodies that are moving have **kinetic energy** (E_K, *KE*), e.g. a flying bird, a shooting star, a moving locomotive, a speeding bullet.

Bodies that can do work because of their position have **potential energy** (E_P, *PE* or *U*), e.g. water in a reservoir, a compressed spring, a stretched rubber band.

Kinetic and potential energy are said to be forms of **mechanical energy**.

Where does this leave chemical, heat and electrical energy? Because they are to do with the random vibrations or motions of electrons, atoms and molecules within an object, they are said to be forms of **internal energy** (E_i). This chapter deals only with mechanical energy. Heat, sound, electricity and nuclear energy are dealt with in later chapters. Chemical energy is mainly left to the other physical science — chemistry.

WORK 9.3

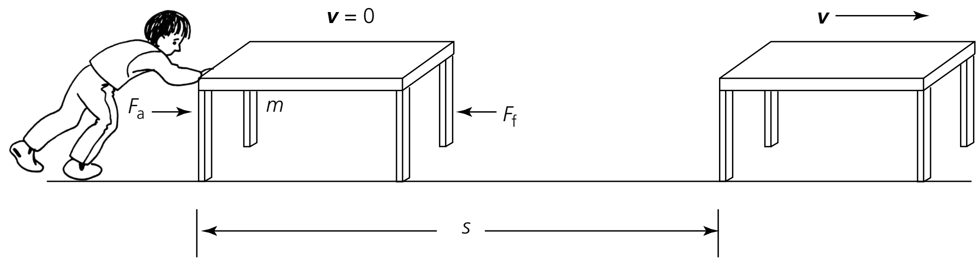

Figure 9.1
The desk with mass *m* is moved from rest a distance *s* across the floor by an applied force ***Fa*** against the frictional force ***F***f. It acquires a velocity v.

NOVEL CHALLENGE

Could you shift a destroyer (a 20 000 tonne ship) moored in a dock with the ropes slack? Let's assume you can apply a force of 500 N. We say 'Yes'; but how long do you think it would take to push it 2 m away from the dock: 400 seconds, 400 hours, or forget it?

If you tried to push a desk across the floor and it didn't move, you might say you did a lot of work on the desk. But to a physicist, if it didn't move then no work was done. If you did move it, then the work done would depend on how hard you pushed and the distance it moved. The word 'work' is often used very loosely; for example, have you done your home*work* tonight? Physicists define work very carefully; **work is defined as the product of the force and the distance moved in the direction of an applied force**. It is a scalar quantity, and yet is the product of two vector quantities.

$$\text{Work} = \text{force} \times \text{displacement} \quad \text{or} \quad W = \mathbf{F}\mathbf{s}$$

Since force is measured in newtons and displacement is measured in metres, work has the units **newton metre** or N m. The newton metre is called the **joule (J)** in honour of James Joule (1818–89), an English physicist who studied heat and electrical energy.

Example

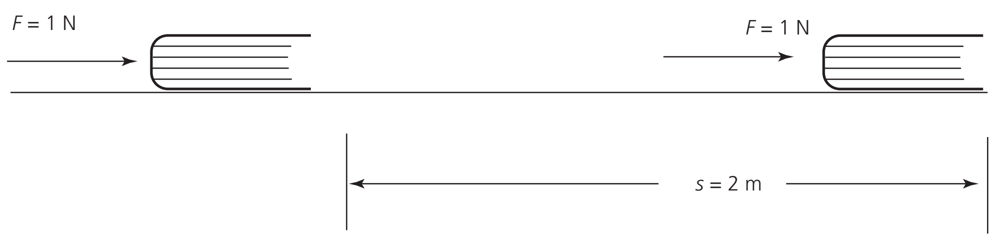

Figure 9.2
Work is done when a force is used to push a book along a desk.

Calculate the work done when a horizontal force of 1 N is used to push a book a distance of 2 m along a desk (Figure 9.2).

Solution

$$W = \mathbf{F}\mathbf{s} = 1\text{ N} \times 2\text{ m} = 2\text{ J}$$