4.1 Energy

The concept of energy emerged in the 19th century. The idea was used to explain the work output of steam engines and then generalised to understand other heat engines. It also became a key tool for understanding chemical reactions and biological systems.

Limits to the use of fossil fuels and global warming are critical problems for this century. Physicists and engineers are working hard to identify ways to reduce our energy usage.

4.1.1 Energy changes in a system, and the ways energy is stored before and after such changes

4.1.1.1 Energy stores and systems

A system is an object or group of objects.

There are changes in the way energy is stored when a system changes.

Students should be able to describe all the changes involved in the way energy is stored when a system changes, for common situations. For example:

- an object projected upwards
- a moving object hitting an obstacle
- an object accelerated by a constant force
- a vehicle slowing down
- bringing water to a boil in an electric kettle.

Throughout this section on Energy students should be able to calculate the changes in energy involved when a system is changed by:

- heating
- work done by forces
- work done when a current flows
- use calculations to show on a common scale how the overall energy in a system is redistributed when the system is changed.

4.1.1.2 Changes in energy

Students should be able to calculate the amount of energy associated with a moving object, a stretched spring and an object raised above ground level.

The kinetic energy of a moving object can be calculated using the equation:

kinetic energy = 0.5 × mass × (speed)^2 *(recall)*

$$\left[E_k = \frac{1}{2} m v^2\right]$$

kinetic energy, E_k, in joules, J
mass, *m*, in kilograms, kg
speed, *v*, in metres per second, m/s

The amount of elastic potential energy stored in a stretched spring can be calculated using the equation:

elastic potential energy = 0.5 × spring constant × $(\text{extension})^2$ *(Physics equation sheet)*

$$\left[E_e = \frac{1}{2} k e^2\right]$$

(assuming the limit of proportionality has not been exceeded)

elastic potential energy, E_e, in joules, J
spring constant, k, in newtons per metre, N/m
extension, e, in metres, m

The amount of gravitational potential energy gained by an object raised above ground level can be calculated using the equation:

g.p.e. = mass × gravitational field strength × height *(recall)*

$$\left[E_p = m\,g\,h\right]$$

gravitational potential energy, E_p, in joules, J
mass, m, in kilograms, kg
gravitational field strength, g, in newtons per kilogram, N/kg

(In any calculation the value of the gravitational field strength (g) will be given.)

height, h, in metres, m

4.1.1.3 Energy changes in systems

The amount of energy stored in or released from a system as its temperature changes can be calculated using the equation:

change in thermal energy = mass × specific heat capacity × temperature change

$$[\Delta E = m\,c\,\Delta\theta]$$

(Physics equation sheet)

change in thermal energy, ΔE, in joules, J
mass, m, in kilograms, kg
specific heat capacity, c, in joules per kilogram per degree Celsius, J/kg °C
temperature change, $\Delta\theta$, in degrees Celsius, °C

The specific heat capacity of a substance is the amount of energy required to raise the temperature of one kilogram of the substance by one degree Celsius.

Required practical activity 1: investigation to determine the specific heat capacity of one or more materials. The investigation will involve linking the decrease of one energy store (or work done) to the increase in temperature and subsequent increase in thermal energy stored.

4.1.1.4 Power

Power is defined as the rate at which energy is transferred or the rate at which work is done.

$$\text{power} = \frac{\text{energy transferred}}{\text{time}}$$

$$\left[P = \frac{E}{t}\right]$$

(both equations, recall)

$$\text{power} = \frac{\text{work done}}{\text{time}}$$

$$\left[P = \frac{W}{t}\right]$$

power, P, in watts, W
energy transferred, E, in joules, J
time, t, in seconds, s
work done, W, in joules, J

An energy transfer of 1 joule per second is equal to a power of 1 watt.

Students should be able to give examples that illustrate the definition of power eg comparing two electric motors that both lift the same weight through the same height but one does it faster than the other.

4.1.2 Conservation and dissipation of energy

4.1.2.1 Energy transfers in a system

Energy can be transferred usefully, stored or dissipated, but cannot be created or destroyed.

Students should be able to describe with examples where there are energy transfers in a closed system, that there is no net change to the total energy.

Students should be able to describe, with examples, how in all system changes energy is dissipated, so that it is stored in less useful ways. This energy is often described as being 'wasted'.

Students should be able to explain ways of reducing unwanted energy transfers, for example through lubrication and the use of thermal insulation.

The higher the thermal conductivity of a material the higher the rate of energy transfer by conduction across the material.

Students should be able to describe how the rate of cooling of a building is affected by the thickness and thermal conductivity of its walls.

Students do not need to know the definition of thermal conductivity.

Required practical activity 2 (physics only): investigate the effectiveness of different materials as thermal insulators and the factors that may affect the thermal insulation properties of a material.

4.1.2.2 Efficiency

The energy efficiency for any energy transfer can be calculated using the equation:

$$\text{efficiency} = \frac{\text{useful output energy transfer}}{\text{total input energy transfer}}$$

(both equations, recall)

Efficiency may also be calculated using the equation:

$$\text{efficiency} = \frac{\text{useful power output}}{\text{total power input}}$$

(HT only) Students should be able to describe ways to increase the efficiency of an intended energy transfer.

4.1.3 National and global energy resources

The main energy resources available for use on Earth include: fossil fuels (coal, oil and gas), nuclear fuel, biofuel, wind, hydro-electricity, geothermal, the tides, the Sun and water waves.

A renewable energy resource is one that is being (or can be) replenished as it is used.

The uses of energy resources include: transport, electricity generation and heating.

Students should be able to:

- describe the main energy sources available
- distinguish between energy resources that are renewable and energy resources that are non-renewable
- compare ways that different energy resources are used, the uses to include transport, electricity generation and heating
- understand why some energy resources are more reliable than others
- describe the environmental impact arising from the use of different energy resources
- explain patterns and trends in the use of energy resources.

Descriptions of how energy resources are used to generate electricity are not required.

Students should be able to:

- consider the environmental issues that may arise from the use of different energy resources
- show that science has the ability to identify environmental issues arising from the use of energy resources but not always the power to deal with the issues because of political, social, ethical or economic considerations.