ENERGY  Types of Energy and Energy Transfers

Energy is the ability to make something useful happen.

Energy comes in a number of different types:

- **Kinetic energy**
  - an object has due to its motion.
- **Chemical energy**
  - can be released when chemical reactions occur (including burning of fuels and the reactions of chemicals in batteries).
- **Elastic potential energy**
  - stored in a material because it is stretched or compressed. It is released when the object returns to its natural shape and size.
- **Gravitational potential energy**
  - stored by objects raised up above the Earth's surface. It is released if the object falls towards the Earth.
- **Nuclear energy**
  - stored in the nucleus of atoms and can be released in nuclear reactions.

Energy transfers can be shown on simple diagrams.

**Transducer:**

- A device that converts one form of energy into another.

**Input energy**

- **Output energy 1**
- **Output energy 2**

Many transducers have a number of output energies. Sometimes we ignore some of these if they are insignificant.

**Whenever something useful happens, energy is transferred.**

**Energy transfers**

- E.g. Candle
  - Chemical energy (in wax) \[\rightarrow\] Heat \[\rightarrow\] Light \[\rightarrow\] (In flame)
- E.g. Electric motor
  - Electrical energy \[\rightarrow\] Kinetic energy \[\rightarrow\] Heat energy \[\rightarrow\] Sound energy (very small so probably ignored)
- Some transfers are cyclical
  - E.g. pendulum
  - Gravitational potential \[\leftrightarrow\] Kinetic \[\leftrightarrow\] Gravitational potential

**Questions**

1. Nuclear energy is stored in the nucleus of atoms. Make a list of the other types of energy that can be stored giving an example of each.
2. What is a transducer? Make a list of five transducers that might be found in a home and the main energy change in each case.
3. Draw an energy transfer diagrams for the following showing the main energy transfers in each case:
   - a. Electric filament light bulb.
   - b. Solar cell.
   - c. Electric kettle.
   - d. Loudspeaker.
   - e. Mobile ‘phone ‘charger’.
   - f. Clockwork alarm clock.
   - g. Playground swing.
   - h. Bungee jumper.
   - i. Petrol engine.
   - j. Microphone.
4. What provides the energy input for the human body? List all types of energy that the body can transfer the energy input into.
Probably the most important idea in Physics is the Principle of Conservation of Energy, which states:

**Energy cannot be created or destroyed. It can only be transformed from one form to another form.**

This means that the total energy input into a process is the same as the total energy output.

We can use a more sophisticated energy transfer diagram, called a **Sankey diagram**, to show this.

- **Questions**
  2. What units is energy measured in?
  3. Explain the difference between energy transformations and energy transfers. Suggest four ways energy can be transferred.
  4. A TV set uses 25 J of energy each second. If 15 J of energy is converted to light and 2 J is converted to sound, how much energy is converted to heat, assuming this is the only other form of energy produced?
  5. The motor in a toy train produces 1 J of heat energy and 2 J of kinetic energy every second. What must have been the minimum electrical energy input per second? If the train runs uphill and the electrical energy input stays the same, what would happen to its speed?
  6. Use the following data to draw a Sankey diagram for each device:
     a. Candle (chemical energy in wax becomes heat energy 80% and light 20%).
     b. Food mixer (electrical energy supplied becomes 50% heat energy in the motor, 40% kinetic energy of the blades, and 10% sound energy).
     c. Jet aircraft (chemical energy in fuel becomes 10% kinetic energy, 20% gravitational potential energy, and 70% heat).
Energy Work Done and Energy Transfer

Whenever something useful happens, energy must be transferred but how can we measure energy? The only way to measure energy directly is by considering the idea of work done.

Work done = force (N) × distance moved in the direction of the force (m).

The energy transferred is always equal to the work done by the force.

Object gains energy

Object loses energy

Work done on the object.

Distance

Force

Object 2

Gains energy

Energy conservation

Work done on Object 2

Object 1

Loses energy

Motion

KE increases

KE increases

Work done by Object 1

Bow does work on the arrow

Force

Gains energy

Elastic potential energy gained by the arrow

Elastic potential energy lost by the bow

Weight

Work done against friction → decrease in kinetic energy

N.B. The distance moved must be along the same line (parallel) as the force.

Motion

Pull of arm

Motion

Push

Work done

Work not done

Work done = +force × distance

Work done against friction = –force × distance

Work done

Work not done

Distance

Force

Force

Distance

Fuel loses chemical energy

Rocket gains kinetic energy

Fuel does work on the rocket

Club does work on the ball

Kinetic energy gained by the arrow

Elastic potential energy gained by the spring

Gravitational potential energy lost by mass

Weight

Mass does work on spring

Work done against friction

KE increases

Friction

Motion

Weight

Work done by gravity

Falls

KE increases

KE increases

Rocket gains kinetic energy

Rocket gains kinetic energy

Gravitational potential energy gained by mass

G Pearl does work on the ball

Golf club loses some kinetic energy

Golf ball gains some kinetic energy

Club does work on the ball

Questions

1. Copy and complete:
   ‘Work is done when a ? moves an object. It depends on the size of the ? measured in ? and the ? the object moves measured in ?. Whenever work is done, an equal amount of ? is transferred. The unit of energy is the ?. Work is calculated by the formula: work = ? × distance moved in the ? of the ?.’
   2. I push a heavy box 2 m along a rough floor against a frictional force of 20 N. How much work do I do? Where has the energy come from for me to do this work?
   3. A parachute exerts a resistive force of 700 N. If I fall 500 m, how much work does the parachute do?
   4. A firework rocket produces a constant thrust of 10 N.
      a. The rocket climbs to 150 m high before the fuel is used up. How much work did the chemical energy in the fuel do?
      b. Explain why the chemical energy stored in the fuel would need to be much greater than the work calculated in (a).
      c. The weight of the empty rocket and stick is 2.5 N. How much work has been done against gravity to reach this height?
      d. The answers to parts (a) and (c) are not the same, explain why.
Questions

1. A kettle converts 62,000 J of electrical energy into heat energy in 50 s. Show its power output is about 1,200 W.
2. A car travels at constant velocity by exerting a force of 1,025 N on the road. It travels 500 m in 17 s. Show that its power output is about 30 kW.
3. The power to three electrical devices is as follows: energy efficient light bulb, 16 W; the equivalent filament bulb, 60 W; a TV on standby, 1.5 W.
   a. How many more Joules of electrical energy does the filament bulb use in one hour compared to the energy efficient bulb?
   b. Which uses more energy, a TV on standby for 24 hours or the energy efficient bulb on for 1.5 hours?
4. When I bring my shopping home, I carry two bags, each weighing 50 N up two flights of stairs, each of total vertical height 3.2 m. I have a weight of 700 N.
   a. How much work do I do on the shopping?
   b. How much work do I do to raise my body up the two flights of stairs?
   c. If it takes me 30 s to climb all the stairs, show that my power output is about 170 W.
ENERGY  Gravitational Potential Energy and Kinetic Energy

Questions
1. Make a list of five objects that change their gravitational potential energy.
2. Using the diagram above calculate the kinetic energy of the car and the lorry.
3. How fast would the car have to go to have the same kinetic energy as the lorry?
4. The mass of the lift and the passengers in the diagram is 200 kg. Each floor of the building is 5 m high.
   a. Show that the gravitational potential energy of the lift when on the eighth floor is about 80 000 J.
   b. How much gravitational potential energy would the lift have when on the third floor? If one passenger
      of mass 70 kg got out on the third floor, how much work would the motor have to do on the lift to
      raise it to the sixth floor?
   c. What is the gravitational potential energy of a 0.5 kg ball 3 m above the surface of the Moon where
      the gravitational field strength is about 1.6 N/kg?
5. A coin of mass 10 g is dropped from 276 m up the Eiffel tower.
   a. How much gravitational potential energy would it have to lose before it hits the ground?
   b. Assuming all the lost gravitational potential energy becomes kinetic energy, how fast would it be
      moving when it hit the ground?
   c. In reality, it would be moving a lot slower, why?
ENERGY  Energy Calculations

All energy calculations use the Principle of Conservation of Energy.

E.g. Bouncing ball

\[ GPE = m \times g \times h \]

\[ KE = \frac{1}{2} mv^2 \]

Ball deforms on impact, heating it

\[ GPE \quad GPE \quad KE \quad KE \]

KE leaving floor \( \frac{1}{2}mv^2 = mgh = GPE \) at \( h \)

KE hitting floor \( \frac{1}{2}mv^1 = mgh_1 = GPE \) at \( h_1 \)

Conservation of energy

GPE at top of bounce = KE at bottom of bounce

\[ mg\Delta h = \frac{1}{2}mv^2 \]

\[ v_1 = \sqrt{2gh} \]

GPE at top of skydive

Work against friction

KE at bottom

GPE on leaving plane = \( mg\Delta h \)

Air resistance is ignored

Elastic potential energy = KE leaving floor = GPE at \( h_2 \)

GPE at top is not equal to KE at bottom as some GPE was transferred to work against friction (air resistance).

\[ GPE = KE + \text{work against friction} \]

\[ mg\Delta h = \frac{1}{2}mv^2 + F \times \Delta h \]

\[ F = \frac{mg\Delta h - \frac{1}{2}mv^2}{\Delta h} \]

At terminal velocity, all the loss in GPE is doing work against air resistance.

Roller Coaster

And a tiny bit of KE to carry the truck over the top, usually ignored

GPE converted to KE

\[ KE \quad KE \quad GPE \quad + \quad KE \]

KE here = loss of GPE from top

\[ \frac{1}{2}mv^2 = mgh_1 \]

\[ v = \sqrt{2gh_1} \]

Time to reach top of track

\[ = \text{GPE gain / power of motor} = \frac{mgh_1}{\text{power}} \]

The time will be greater than this as some electrical energy is converted to KE and does work against friction.

Questions

1. At the start of a squash game, a 44 g ball is struck by a racquet and hits the wall at 10 m/s.
   a. Show its KE is about 2 J.
   b. The ball rebounds at 8 m/s. Calculate the loss in KE.
   c. Where, and into what form, has this energy been transferred?
   d. An acrobatics aircraft of mass 1000 kg is stationary on a runway. Its takeoff speed is 150 m/s.
      a. Show that the KE of the aircraft at take off is about \( 11 \times 10^6 \) J
      b. The maximum thrust of the engines is 20 000 N. Show the aircraft travels over 500 m along the runway before it lifts off.
      c. Give two reasons why the runway will actually need to be considerably longer.
      d. The aircraft climbs to a height of 1000 m. Show it gains about \( 10 \times 10^6 \) J.
      e. If the aircraft takes 5 minutes to reach this height, show the minimum power of the engine must be about 33 kW.
      f. Why must this be the minimum power?
      g. The aircraft then flies level at 200 m/s. What is its KE now?
      h. The aircraft then leaves the runway at 200 m/s. What is its KE now?
      i. Hence, what is the maximum speed the aircraft could now be travelling at?
      j. In reality, it will be travelling slower, why?
ENERGY  Efficiency and the Dissipation of Energy

If energy is conserved, why do we talk about ‘wasting energy’?

Usually when energy is transferred only a proportion of the energy is converted to a useful form, the remainder is converted to other less useful forms of energy, often heat.

E.g. Light bulb

Useful – the type of energy we want from a light bulb.

This energy is not useful – light bulbs are not designed to be heaters. We say this energy has been ‘wasted’.

We say that this energy, that is not useful, is ‘wasted’.

The proportion of the total energy transferred that is useful is called the efficiency of the system.

Efficiency (%) = useful energy output (J) / total energy input (J) × 100%

E.g. Power generation

Heat losses due to friction in moving parts of power station, e.g. smoke, cooling water

Notice that most of the wasted energy ends up as heat.

Questions

1. An electric motor on a crane raises 50 kg of bricks 10 m. If the energy supplied to the motor was 16 000 J show that the motor is about 30% efficient.

2. A rollercoaster has 250 000 J of GPE at the top of the first hill. At the bottom of the first hill, the coaster has 220 000 J of KE. Where did the rest of the energy go, and what is the overall efficiency of the energy go, and what is the overall efficiency of the GPE to KE conversion?

3. A ball of mass 30 g falls from 1.5 m and rebounds to 0.8 m. Show that the efficiency of the energy transformation is about 50%. Why do you not need to know the mass of the ball?

4. A car engine is about 20% efficient at converting chemical energy in petrol. If a car of mass 1000 kg has to climb a hill 50 m high, how much chemical energy will be required? Why in reality would substantially more chemical energy be needed than the value you calculated?

5. A filament light bulb produces a lot of waste heat. Explain why this waste heat energy cannot be put to other uses very easily.

6. What are the main sources of energy wastage in:
   a. A vacuum cleaner?
   b. A motor car?