5 Energy

Study Station ▸▸

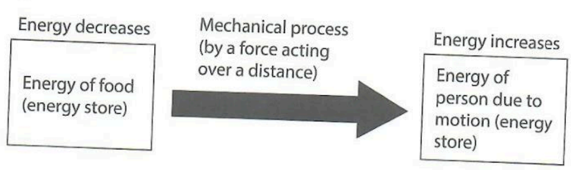
A Energy Stores, Transfer and Conservation

Learning Outcomes

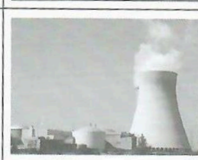
- Understand that there are different types of energy stores.
- Understand that energy can be transferred from one store to another store.
- Recall and apply *kinetic energy* $KE = \frac{1}{2}mv^2$ and *gravitational potential energy near Earth's surface* $GPE = mgh$ to real-world situations and solve related problems.
- State the principle of conservation of energy and apply to real-world situations and solve related problems.

1. **Energy** is a measure of the capacity to do work. It is a physical quantity that can be transferred from one store to another store, through various processes using different mechanisms.
2. When you start jogging, you are *using energy to move your body from a stationary position.*

- The energy that you use comes from the food that you have eaten.
- When you start to jog, you are *exerting a force* to accelerate *over a distance.*
- When you accelerate, your speed increases. The energy that is associated with your motion also increases.



3. The table below shows the various **energy stores** in different forms.

Energy Store	Example of Object With the Energy Store	
The **kinetic store** is associated with motion.		• A fan has energy in the kinetic store when it is spinning. • If the fan spins faster (more energy), it can blow a piece of paper further away (more work).
The **gravitational potential store** is associated with the height of the object's position.		• A book has energy in the gravitational potential store when it is located at a height above the ground. • If the book is placed higher (more energy), it will fall a greater distance to reach the floor (more work).
The **chemical potential store** is associated with chemical bonds.		• A rechargeable battery has energy in the chemical potential store when it is charged. • If the battery is charged more (more energy), it can run a device for a longer period of time (more work). • Other examples include food and vehicle fuel (e.g. petrol).
The **elastic potential store** is associated with the stretchability of a material.		• A rubber band has energy in the elastic potential store when it is stretched. • If the rubber band is stretched more (more energy), it can fly further (more work).
The **internal (thermal) store** is associated with temperature and the state of matter (solid, liquid or gas state).		• A kettle of water has energy in the internal store which is the energy of the water molecules due to their motion and interactions. • If the kettle of water is heated up (more energy), the water molecules move or interact more energetically.
The **nuclear store** is associated with the stability of the nuclei in atoms.		• A nuclear power plant can transfer energy from the nuclei of nuclear fuel (e.g. uranium) to generate electricity.

4. The value of energy can be determined by the amount of work that can be done.
   - The SI unit of energy is **joule (J)**.
   - It is a *scalar quantity.*
5. The energy in the kinetic store is also known as **kinetic energy KE**.
   - KE is associated with the motion of an object.
   - KE of an object of mass *m* moving at a speed *v* is given by:

$$KE = \frac{1}{2}mv^2$$

   - If an object is stationary ($v = 0$), its KE is zero.

Common Misconception

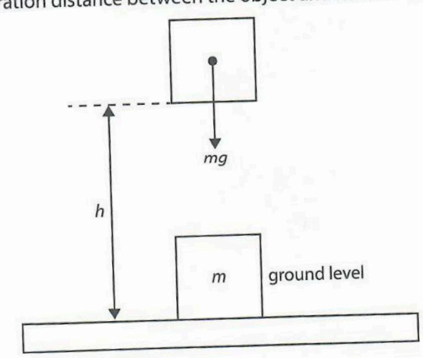
✗ Kinetic energy is a vector quantity. Its direction is the same as the direction of motion of the object.

✓ Kinetic energy is a scalar quantity and does not have direction. Its magnitude depends on mass and speed (which is equal to the magnitude of velocity).

6. The energy in the gravitational potential store is also known as **gravitational potential energy GPE**.
   - GPE is the capacity to bring two masses closer together (due to the attractive gravitational force).
   - GPE of an object of mass *m*, at height *h* near Earth's surface, with gravitational field strength *g*, is given by:

$$GPE = mgh$$

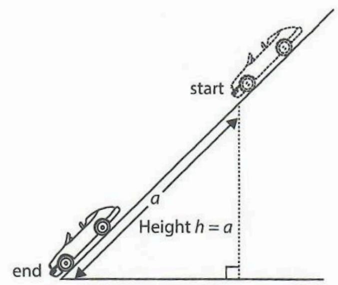
   - Height *h* is the separation distance between the object and Earth's surface.



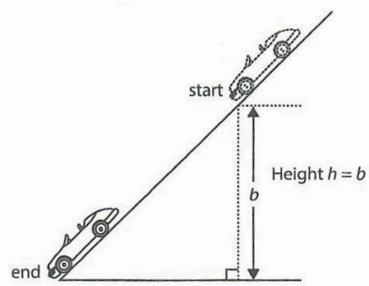
   - If an object is on the ground ($h = 0$), its GPE is zero.

Common Misconception

✗ The height h (in GPE = mgh) refers to the distance travelled from the starting point to the ending point.



✓ The height h (in GPE = mgh) is measured as the vertical displacement between the starting point and the ending point.



Explanation

Height h is not affected by the path travelled from starting point to ending point. Height h is equivalent to b.

Worked Example 5.1

Jet fuel is pumped into an aeroplane before it takes off.

(a) State the energy store of the jet fuel.

(b) State two other energy stores that have energy when the aeroplane is flying.

(c) State the change of amount of energy in these two stores as the aeroplane takes off.

Solution

(a) Chemical potential store

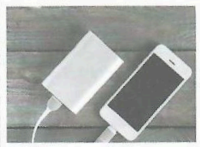
(b) The aeroplane is moving, so it has energy in the kinetic store.

The aeroplane is flying at a certain height above the Earth's surface, so it has energy in the gravitational potential store.

(c) As the aeroplane takes off, its speed v and height h increase.

From $KE = \frac{1}{2}mv^2$ and GPE = mgh, we know that KE increases and GPE increases.

7. The table below shows how energy can be transferred from one energy store to another energy store through various pathways using different processes.

Pathway	Example of Energy Transfer Process	
Mechanical pathway Energy is transferred mechanically by a *force acting over a distance.*		• A car engine consumes petrol to generate a force to accelerate the car over a distance. • Energy is transferred from the petrol (chemical potential store) to the car (kinetic store).
Electrical pathway Energy is transferred by an *electric current flowing.*		• A power bank generates an electric current that flows to the phone. • Energy is transferred from the power bank (chemical potential store) to the phone battery (chemical potential store).
Thermal pathway Energy is transferred by *heating due to a temperature difference.*		• Hot charcoal heats up food placed nearby. • Energy is transferred from the charcoal (internal store) to the food (internal store).
Propagation of waves Energy is transferred by the *propagation of mechanical and electromagnetic waves*		• A vibrating guitar string creates sound waves (mechanical waves) which travel and cause our eardrums to vibrate. • Energy is transferred from the guitar strings (kinetic store) to our eardrums (kinetic store).

Tip

Energy cannot be created or destroyed. Energy can only be transferred from one energy store to another energy store.

8. The **principle of conservation of energy** states that **the total energy of an isolated system is constant**.
   - An **isolated system** does not interact with the outside of the system. It experiences *no external force* and allows *no mass or energy to be transferred in or out*.
   - The total energy of an isolated system remains the same at all times.
   - Processes can occur in the system which transfer energy from one part to another part of the system. However, the sum of energy of all parts of the system remains the same.

     Total initial energy = total final energy

   - In the real world, systems are not completely isolated. Most experience friction and air resistance as external forces. Energy is transferred from the system to the molecules in the surroundings (which can lead to a higher temperature).

Worked Example 5.2

A car engine generates a force to move the car forward against air resistance. The car is moving at constant speed on flat land.

Energy is transferred from the petrol (chemical potential store) to the ________.

A car (kinetic store)

B car (kinetic store) and environment (internal store)

C environment (internal store)

D car (gravitational potential store)

Strategy

The car's speed is constant, KE remains constant. Options **A** and **B** are wrong.

The car is moving on flat land, GPE remains constant. Option **D** is wrong.

Solution

C

Explanation

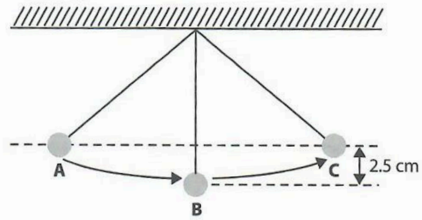
The car (with engine and petrol) is not an isolated system, so the total energy of the car is not constant (energy is transferred from petrol).

The car and its surroundings are an isolated system, so the sum of energy of the car and energy of the environment is constant (energy loss of petrol = energy gain of environment).

Worked Example 5.3

A pendulum is released from rest at position **A**. It swings past position **B**, which is 2.5 cm lower than position **A** and reaches position **C**, which is horizontally level with position **A**.

(Take the acceleration of free fall g to be 10 m/s^2)



Using the principle of conservation of energy, calculate the speed of the pendulum at position **B**. Assume negligible friction and air resistance.

Strategy

Note that the energy of the pendulum can be in kinetic and gravitational potential stores.

Using the principle of conservation of energy, we get total energy = KE + GPE = constant

	At Position A	At Position B	At Position C
KE	0 (pendulum is stationary)	maximum	0 (pendulum is stationary)
GPE	maximum (maximum height)	minimum (minimum height)	maximum (maximum height)

Solution

(a) When the pendulum moves from **A** to **B**, its KE increases while its GPE decreases.

Using the principle of conservation of energy,

$$\text{increase in KE} = \text{decrease in GPE}$$

$$\frac{1}{2}mv^2 - 0 = mgh_{\text{maximum}} - mgh_{\text{minimum}}$$

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

$$v^2 = 2g\Delta h$$

$$v = \sqrt{2g\Delta h}$$

$$= \sqrt{2 \times 10 \text{ m/s}^2 \times 0.025 \text{ m}}$$

$$= \sqrt{0.5 \text{ m}^2/\text{s}^2} = 0.71 \text{ m/s (2 sig. fig.)}$$

Link Discover Physics (5th Edition) Textbook — Section 6.1

Checkpoint 5.1

1. A stationary object of mass 2 kg is dropped from a height of 30 m. Calculate its kinetic energy when it hits the ground. Ignore air resistance. (Take the acceleration of free fall g to be 10 m/s^2)

B Work and Power

Learning Outcomes

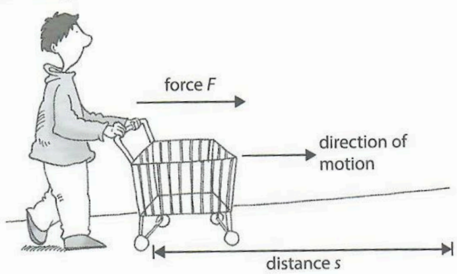
- Recall and apply *work done = force × distance moved in the direction of the force* to real-world situations and solve related problems.
- Recall and apply *power = energy transfer / time taken* to real-world situations and solve related problems.

1. **Work done W** on an object is defined as the **product of force F** acting on the object **and distance travelled s** by the object **in the direction of the force**.

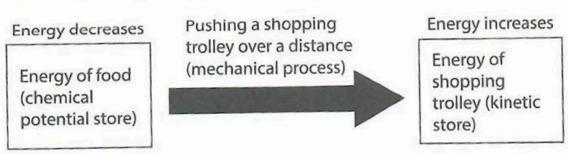
$$W = Fs$$

- Its SI unit is **joule (J)**, which is also the unit of energy.
- It is a scalar quantity, like energy.

2. When you use energy to push a shopping trolley (exert a force F) over a distance s, you are doing work on the shopping trolley.



- The work done by you is equal to the energy transferred from the food that you have eaten (chemical potential store).
- The work done on the trolley is equal to the energy transferred to the trolley (kinetic store).



Tip

We can derive the formula GPE = mgh using work done.
Consider an object of mass m initially at rest at a height h in free fall to the ground.
Energy transferred from gravitational potential store = work done by gravitational force
= force F × distance travelled in the direction of force s
= weight W × height h
= mgh

- **Worked Example 5.4**

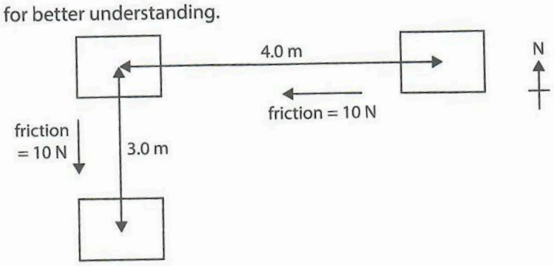
Smart warehouses use robots that can move boxes independently.

A warehouse robot uses energy from its battery to move a load of 50 kg. It moves on a rough surface 3.0 m to the North and then 4.0 m to the East at a constant speed. There was a constant friction of 10 N. Calculate the total amount of work done against friction.

Strategy

Note that the direction of force against friction (exerted by the robot) is the opposite direction of friction.

Draw a diagram for better understanding.



Solution

Total amount of work done W against friction $= (10\text{ N} \times 3.0\text{ m}) + (10\text{ N} \times 4.0\text{ m})$
$= 70\text{ J}$

Explanation

Note that in $W = Fs$ we use distance travelled (3.0 m and 4.0 m) and not displacement.

Common Error

✗ An object of weight 50 N is moved horizontally by 5 m. The work done by the weight is $50\text{ N} \times 5\text{ m} = 250\text{ J}$.

✓ An object of weight 50 N is moved horizontally by 5 m. The work done by the weight is $50\text{ N} \times 0\text{ m} = 0\text{ J}$.

Explanation

The distance travelled in the direction of the weight (which is vertical) is zero.

Test Station ▸▸

1. Figure 6.1 shows a hydroelectric dam. Water flows from a higher location to a lower location.

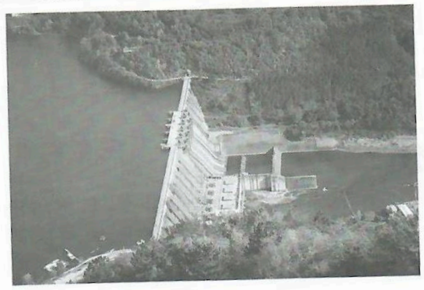


Figure 6.1

Which of the following represents the main energy transfer happening at a hydroelectric dam?

	Body (Energy Store)	Process	Body (Energy Store)	Process
A	Flowing water (kinetic store)	Pushing turbine blades	Electricity generator (kinetic store)	Electric current flowing
B	Hot water (internal store)	Pushing turbine blades	Electricity generator (kinetic store)	Electric current flowing
C	Hot water (internal store)	Heating up electricity generator	Electricity generator (kinetic store)	Electric current flowing
D	Water (chemical potential store)	Propagation of water waves	Electricity generator (kinetic store)	Electric current flowing

2. Figure 6.2 shows a light bulb labelled 10 W, which has been switched on for 4 hours. Calculate how much energy has been used.

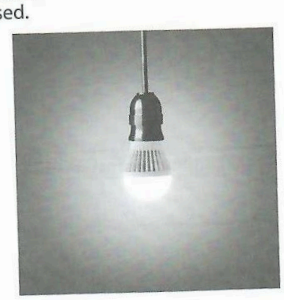


Figure 6.2

A 10 J

B 40 J

C 2400 J

D 144 000 J

3. Power is defined as the rate of work done or rate of energy transfer.
   - The **power P when work W is done or energy E is transferred during a time period t** is given by:

$$P = \frac{W}{t} = \frac{E}{t}$$

   - Its SI unit is **watt (W)** or joules per second (J/s).
   - It is a scalar quantity.

Worked Example 5.5

An elevator at maximum capacity can carry people with a total weight 6000 N to a height of 10 m in 12 s. Calculate the power generated by the elevator.

Solution

When the elevator moves up, energy is transferred to a gravitational potential store.
Increase in $GPE = mg\Delta h$

Thus, power generated $P = \frac{E}{t} = \frac{mg\Delta h}{t}$

$$= \frac{6000\ \text{N} \times 10\ \text{m}}{12\ \text{s}} = 5000\ \text{W}$$

Tip

Summary notes for this chapter:

- Energy is the capacity to do work.
- Energy stores include kinetic, potential (gravitational, chemical, elastic), internal and nuclear.
- Energy is transferred through pathways, such as mechanical, electrical, thermal and wave propagation.
- Kinetic energy: $KE = \frac{1}{2}mv^2$
- Gravitational potential energy $GPE = mgh$
- Principle of conservation of energy: total initial energy = total final energy
- Work done $W = Fs$
- Power $P = \frac{W}{t} = \frac{E}{t}$

Link Discover Physics (5th Edition) Textbook — Section 6.2

Checkpoint 5.2

1. An engine can provide the energy to a bus to do 2000 kJ of work in 10 s. Calculate the power of the engine.

3. Figure 6.3 shows how Tarzan, whose mass is 85 kg, needs to swing across a piranha-infested river to save Jane from danger. Point **C** is 0.2 m higher than point **A** and point **B** is 0.1 m lower than point **A**.

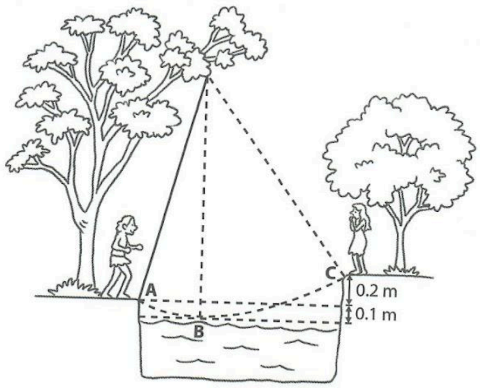


Figure 6.3

(a) Calculate the minimum speed at which Tarzan must swing from point **A** to reach Jane at point **C**. (Assume negligible air resistance.) [3]

(b) Calculate the maximum speed reached by Tarzan during his swing from point **A** to point **C** using the minimum speed obtained in (a). [4]

(c) If wind is blowing from **C** to **A**, how will the minimum speed in (a) be affected? [4]

4. Figure 6.4 shows a drone that flies using four motors known as propellers. Each propeller can exert a maximum upward force of 5 N. The drone can carry a maximum load from the ground to a height of 10 m.

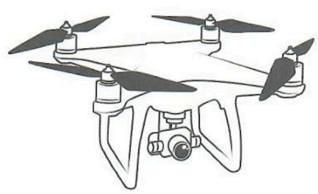


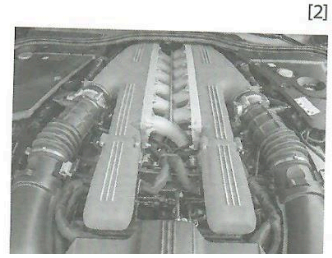
Figure 6.4

(a) Calculate the increase in gravitational potential energy. [2]

(b) It takes 2 s to fly from the ground to a height of 10 m. Calculate the power supplied by its battery. [2]

(c) Calculate the work done by each propeller. [2]

5. The V-12 engine is a well-known type of engine commonly used in very fast cars. It can provide 400 kW to a car of mass 1.5 Mg during acceleration.



(a) The top speed of the car is 80 m/s. Calculate its kinetic energy at this speed. [2]

(b) Calculate how long the car needs to take to accelerate from rest to the top speed. [2]