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الوحدة الاولي: المجالات الكهربائية - انسباير	1
المراجعة الشاملة وفق الهيكل الوزاري منهج انسباير Inspire بدون الحل	2
المراجعة الشاملة وفق الهيكل الوزاري منهج بريدج Bridge بدون الحل	3
شرح وتدريبات وفق الهيكل الوزاري الجديد مع الإجابات	4
مراجعة نهائية وفق الهيكل الوزاري الجديد منهج انسباير باللغتين العربية والانجليزية	5

تحميل تطبيق المناهج للهواتف الذكية	
تطبيق المناهج على Store App (آبل)	تطبيق المناهج على Play Google (أندرويد)

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Einstein of the Arabs

مصدرك الأول

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الكاملة

فى الفيزياء



استاذ

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Einstein_AE

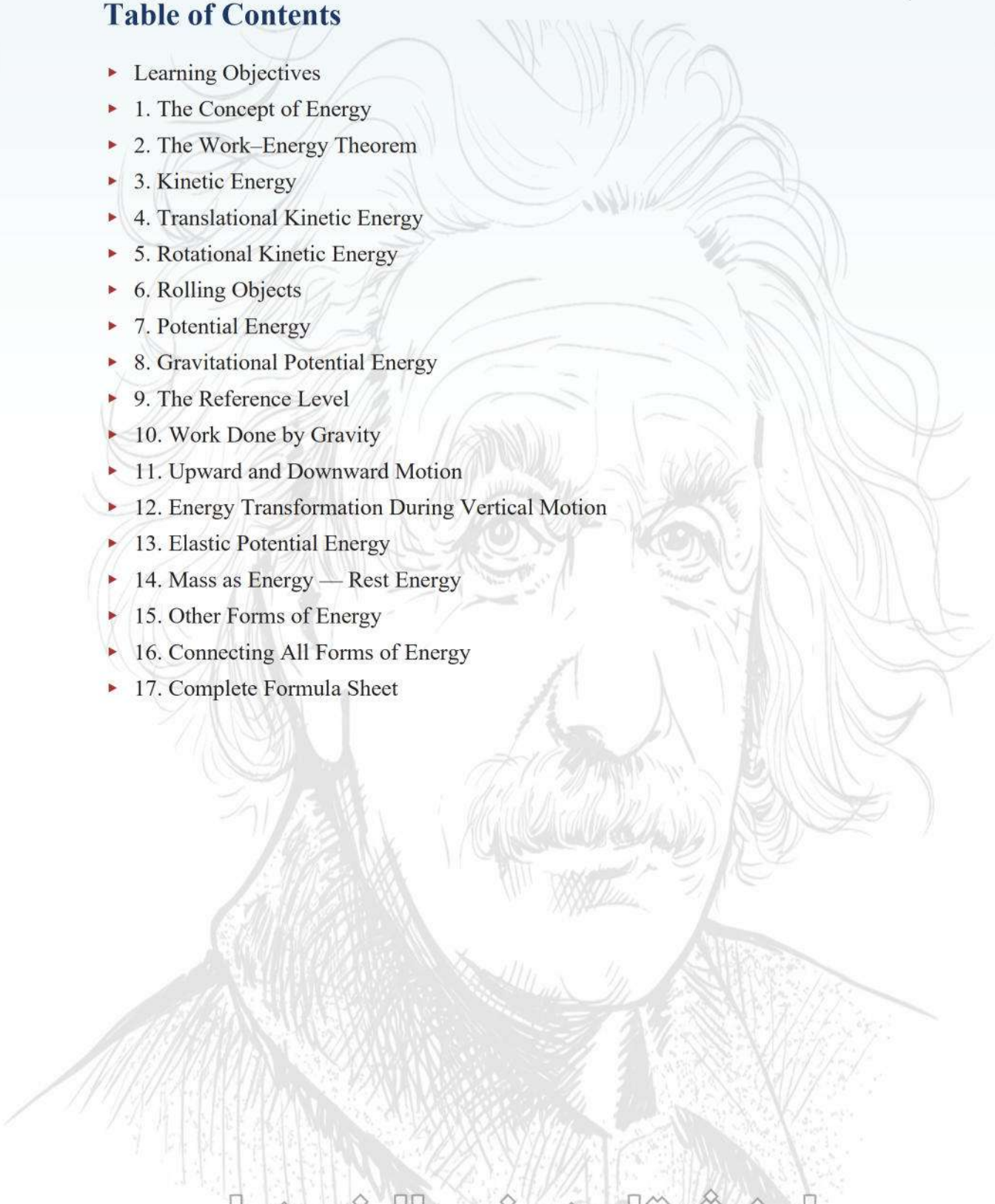
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Einsteinabdo

معك خطوة بخطوة
نحو التفوق والتميز

Table of Contents

- Learning Objectives
- 1. The Concept of Energy
- 2. The Work–Energy Theorem
- 3. Kinetic Energy
- 4. Translational Kinetic Energy
- 5. Rotational Kinetic Energy
- 6. Rolling Objects
- 7. Potential Energy
- 8. Gravitational Potential Energy
- 9. The Reference Level
- 10. Work Done by Gravity
- 11. Upward and Downward Motion
- 12. Energy Transformation During Vertical Motion
- 13. Elastic Potential Energy
- 14. Mass as Energy — Rest Energy
- 15. Other Forms of Energy
- 16. Connecting All Forms of Energy
- 17. Complete Formula Sheet



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Learning Objectives

This lesson addresses the following Subject Learning Outcomes (SLOs) and their associated Key Performance Indicators (KPIs).

PHY.6.2.03.002

Subject Learning Outcome: Develop an experiment or a simulation to explore the relationship between mechanical work done on an object and its kinetic energy — work–energy theorem.

- **KPI 1.** Recall that when an agent performs work on a system, the system's energy increases, and vice versa.
- **KPI 2.** Classify kinetic energy into translational or rotational kinetic energy.
- **KPI 3.** Recall that translational kinetic energy is proportional to the square of the object's speed.

PHY.6.1.02.047

Subject Learning Outcome: Develop a mathematical model to evaluate the rotational kinetic energy of a rigid object, like a rolling sphere or cylinder or a rolling tire of a vehicle.

- **KPI 4.** Relate the rotational kinetic energy to the object's moment of inertia and its angular velocity: $K_{rot}=(1/2)I\omega^2$.
- **KPI 5.** Calculate the translational and rotational kinetic energies for objects.
- **KPI 6.** Solve problems involving translational and rotational kinetic energy.

PHY.6.2.03.003

Subject Learning Outcome: Develop a mathematical equation to obtain the mechanical work done by the gravitational force on an object moving in the gravitational field.

- **KPI 10.** Calculate the work done by the gravitational force (Wg) when an object is lifted or lowered from a reference level: $Wg = mg(hi - hf)$.

PHY.6.2.03.004

Subject Learning Outcome: Describe the mechanical work of a conservative force in terms of the change in potential energy, and the mechanical work done by a nonconservative force in terms of the change in total mechanical energy.

- **KPI 7.** Define potential energy as the energy stored due to interactions between objects in a system.
- **KPI 8.** Define the term gravitational potential energy.
- **KPI 9.** Relate gravitational potential energy to the mass of the object and its height above or below a reference level: $GPE = mgh$.
- **KPI 11.** Show that the work done by gravity on a body is opposite to the change in gravitational potential energy of the system (body–Earth) as the body moves from an initial position to a final position: $Wg = mg(hi - hf) = -mg(hf - hi) = -\Delta(GPE)$.
- **KPI 12.** Discuss energy transformations in situations where an object moves vertically upward or downward.
- **KPI 13.** Define the term elastic potential energy and give examples.
- **KPI 14.** Interpret mass as a form of energy called rest energy, which is equal to the mass multiplied by the speed of light squared: $E=mc^2$.
- **KPI 15.** Identify other forms of energy like chemical, nuclear, thermal, electrical, and radiant energy and give examples.

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1. The Concept of Energy

What is Energy?

Energy is the **ability of a system to produce a change** in itself or in the world around it.

In simple terms, a system has **energy** if it has the ability to **cause something to happen**

for example, to **move an object**, **raise an object**, **heat something**, or produce another **physical change**.

SI Unit of Energy

The SI unit of energy is the **joule (J)**.

$$1\ \text{J} = 1\ \text{N} \cdot \text{m}$$

Since:

$$1\ \text{N} = 1\ \text{kg} \cdot \text{m/s}^2$$

then:

$$1\ \text{J} = 1\ \text{kg} \cdot \text{m}^2/\text{s}^2$$

Therefore, **work and energy have the same SI unit: the joule**.



2. The Work–Energy Theorem

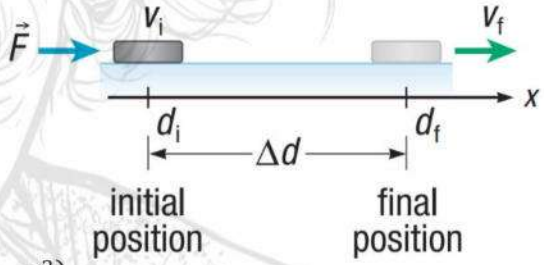
KPI 1

The fundamental relationship in this lesson is the **Work–Energy Theorem**:

> ◆ **Note** — When **work** is done on a **system**, the result is a **change in the system's energy**.

Mathematically:

$$W = \Delta E$$



For a mechanical system in which the change is in kinetic energy:

$$W = \Delta\text{KE} \Rightarrow W = \text{KE}_f - \text{KE}_i$$

Therefore:

$$W = \Delta\text{KE} = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2 = \frac{1}{2}m(v_f^2 - v_i^2)$$

For Deeper Understanding

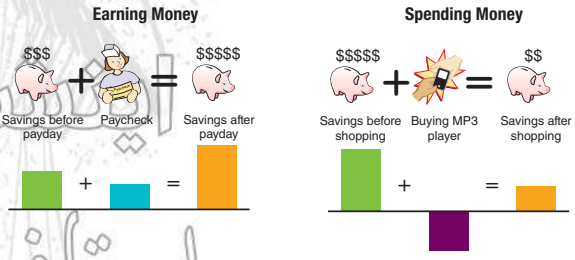
Keeping track of energy changes is a lot like keeping track of a **savings account**:

the amount you have changes when you **earn** or **spend** money.

Energy bar diagrams work the same way

the **height of a bar** represents how much **energy (or work)** is involved,

making it easy to see energy being **gained** or **lost**.



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2.1 Direction of Energy Transfer

Work represents a process through which **energy is transferred** between a **system** and its **surroundings**.

$$\textit{Surrounding} \xrightarrow{\text{Work Done ON the System } (W>0)} \textit{System} \quad \textit{(Energy of the system Increases: } +\Delta E\textit{)}$$

$$\textit{System} \xrightarrow{\text{Work Done BY the System } (W<0)} \textit{Surroundings} \quad \textit{(Energy of the system Decreases: } -\Delta E\textit{)}$$

Work done ON the system

If the **surroundings** (the external world) do **work on the system** $W > 0\ (+)$ **energy is transferred TO the system**, so the change in energy is **positive**$(+\Delta E)$..

Examples:

- Throwing a ball.
- Pushing a car.
- Accelerating an object.



1. Throwing a ball. 2. Pushing a car. 3. Accelerating an object.

Work done BY the system / negative work on the system

If the **system** does **work on the surroundings** (the external world), $W < 0(-)$ **energy is transferred FROM the system**, so the change in energy is **negative**.

Examples:

- Catching a moving ball.
- Braking a car.
- Friction slowing an object.



• Catching a moving ball. • Braking a car. • Friction slowing an object.

For Deeper Understanding This is really **Newton's Second Law** written in terms of **energy**. A **net force** accelerates an object ($F = ma$), and the **work** that force does over a distance ($W = Fd$) equals the resulting **change in kinetic energy** that is exactly the statement that **net work** equals the **change in kinetic energy**.

2.2 Energy-Bar Interpretation



Throwing a ball

If the ball starts from rest:$\mathrm{KE}_i = 0$

Positive work is done on the ball:

$$\mathrm{KE}_i + W = \mathrm{KE}_f \Longrightarrow 0 + W = \mathrm{KE}_f \Longrightarrow W = \mathrm{KE}_f$$

(Result: Positive work increases the ball's kinetic energy). **The ball gains kinetic energy.**

Positive work adds energy to the ball. The ball accelerates and speeds up (v ↑).



Catching a ball

The ball initially has kinetic energy.

The force applied while catching it is opposite to its motion, so the work is negative: $\mathrm{KE}_f = 0$

$$\mathrm{KE}_i + W = \mathrm{KE}_f \Longrightarrow \mathrm{KE}_i + W = 0 \Longrightarrow W = -\mathrm{KE}_i$$

(Result: Negative work completely removes kinetic energy from the ball).

Thus, the negative work removes kinetic energy from the ball..

Negative work removes energy from the ball. The ball decelerates and comes to rest (v = 0).

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✓ Quick Check

Q1 Which of the following is **NOT** a unit of **energy**?

ⓐ J Ⓑ N·m © kg·m²/s² Ⓓ N·m²

Q2 Nada Abdullah Al-Marri and Sarah Mohamed Abdellah are two students in grade 12 advanced, arguing about the physics law equivalent to this expression: $\Delta KE = W$
They consider four laws. Which of the laws is correct based on your study?

ⓐ Newton's third law Ⓑ Newton's second law

© Newton's first law Ⓓ Newton's law of universal gravitation

Q3 According to the Work–Energy Theorem, which of the following is not correct?

ⓐ If the external world does work on a system, W is positive, and the energy of the system increases.

Ⓑ Work done on a system is equal to the change in the system's energy.

© If the external world does work on a system, W is negative, and the energy of the system decreases.

Ⓓ If a system does work on the external world, W is negative, and the energy of the system decreases.

Q3 A **ball is moving** to the right. A student catches the ball and **brings it to rest**. During the catching process, the **force** exerted by the student on the ball is **opposite** to the ball's motion.



Which statement correctly describes what happens to the ball?

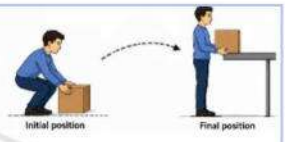
ⓐ **Positive work** is done on the ball, so its **kinetic energy increases**.

Ⓑ **Negative work** is done on the ball, so energy is **transferred from** the ball and its **kinetic energy decreases**.

© **No work** is done because the ball eventually comes to rest.

Ⓓ **Negative work** is done on the ball, so energy is **transferred to** the ball and its **kinetic energy increases**.

Q3 A person **slowly lifts** a heavy box from the floor to a higher shelf.
Consider the **box as the system**.



Which statement correctly describes the energy transfer during this process?

ⓐ The **system does work** on the surroundings, so energy is **transferred from** the box and its **energy decreases**.

Ⓑ The **surroundings do work** on the system, so energy is **transferred to** the box and its **energy increases**.

© **No work** is done because the box moves at a constant speed.

Ⓓ The surroundings do **negative work** on the system, so the **energy** of the box **decreases**.

Q3 In which of the following cases is the **net work done on a moving car equal to zero**?



ⓐ When the car moves with **constant velocity**.

Ⓑ When the car moves with **decreasing velocity**.

© When the car moves with **constant acceleration**.

Ⓓ When the car moves in the **opposite direction to the net force**.

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3. Kinetic Energy

KPI 2 AND KPI 3

Kinetic energy is the energy associated with an object's motion.

There are two main types:

1. Translational Kinetic Energy

Energy associated with an object's translational motion.

$$KE_{trans} = \frac{1}{2}mv^2$$

2. Rotational Kinetic Energy

Energy associated with rotation about an axis.

$$KE_{rot} = \frac{1}{2}I\omega^2$$

✓ **Quick Check**

Q3 Which of the following examples shows **kinetic energy**?

ⓐ A river flowing down a hill
Ⓑ The battery of a light flash
© A golf ball placed at the edge of the hole
Ⓓ Energy stored in a bow and arrow

4. Translational Kinetic Energy

KPI 2 AND KPI 3

Translational kinetic energy is the energy an object has because of its motion from one position to another.

$$KE_{trans} = \frac{1}{2}mv^2$$

where:

- K_{trans} = translational kinetic energy, in joules.
- m = mass, in kilograms.
- v = speed, in meters per second.

Unit Conversions

- Mass (m) must always be in kilograms (kg): g ÷ 1000 → kg
- Speed (v) must always be in metres per second (m/s): km/h ÷ 3.6 → m/s

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Worked Examples

Sample Problem 1 A car has a mass of $1.50 \times 10^3\ kg$ and is travelling at a speed of $85.0\ km/h$. Calculate the car's kinetic energy (KE).

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$m = 1.50 \times 10^3$ kg, $v = 85.0$ km/h

1. CONVERT SPEED TO m/s

$$v = 85.0 \times \left(\frac{1000\,m}{60 \times 60\,s}\right) = 23.6\,m/s$$

2. CALCULATE KINETIC ENERGY

$$KE = \tfrac{1}{2}\,m\,v^2 = \tfrac{1}{2}\,(1.50 \times 10^3\,kg)(23.6\,m/s)^2$$

$$\boldsymbol{KE = 4.18 \times 10^5\,J}$$

Sample Problem 2 When fleeing a predator, a 1.4 kg rabbit has a kinetic energy of 96 J. Calculate the speed (v) of the rabbit.

GIVEN

$$m = 1.4\,kg, \qquad KE = 96\,J$$

RELATIONSHIP

$$v = \sqrt{\frac{2 \cdot KE}{m}}$$

SUBSTITUTION

$$v = \sqrt{\frac{2(96\,J)}{1.4\,kg}} \approx \mathbf{12\ m/s}$$

4.1 Effect of Mass

From: $\mathrm{KE_{trans}} = \frac{1}{2}mv^2$

we see that:

dependence on Mass $\mathrm{KE_{trans}} \propto m$**:** KE is directly proportional to mass

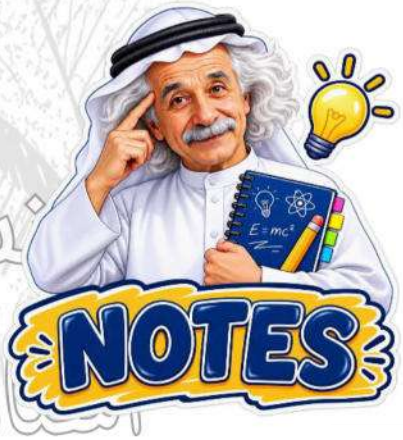
If $m \rightarrow 2m$ (speed constant): $\mathrm{KE}' = 2\mathrm{KE}$ *(Doubling mass doubles kinetic energy)*.

For example, a **7.26-kg bowling ball** thrown through the air has **more kinetic energy** than a **0.148-kg baseball** moving at the **same speed**, simply because **kinetic energy is proportional to mass**.

4.2 Effect of Speed

Dependence on Speed $\mathrm{KE_{trans}} \propto v^2$ **:** KE is directly proportional to the square of velocity (v^2)

Velocity Change	Effect on Kinetic Energy
v	KE (original)
2v (doubles)	4·KE (4 times greater)
3v (triples)	9·KE (9 times greater)
½v (halved)	¼·KE (¼ of its original value)



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Ratio Formulas for Kinetic Energy

Many problems ask for the ratio of two kinetic energies rather than an absolute value.

The general ratio form of the kinetic energy equation is:

Core rule: "Cancel out any constant!"

1. **The constant numerical factor ½ is always cancelled out when setting up ratios.**
2. **Any physical quantity that remains constant (unchanged) in the problem is also cancelled out (= 1).**

$$\frac{KE_1}{KE_2} = \left(\frac{m_1}{m_2}\right) \times \left(\frac{v_1}{v_2}\right)^2$$

For example, a car moving at 20 m/s has **four times** the kinetic energy of the same car moving at 10 m/s.

✓ Quick Check

Q4 An ant of mass **5 g** crawls along a straight line at a constant speed of **0.2 m/s**. Calculate its **kinetic energy**.



ⓐ 1×10^{-1} J Ⓑ 5×10^{-4} J © 1×10^{-4} J Ⓓ 2×10^{-4} J

Q5 A truck of mass **2000 kg** travels along a straight highway at a constant speed of **72 km/h**. Calculate its **kinetic energy**.



ⓐ 5.184×10^{6} J Ⓑ 4×10^{5} J © 2×10^{4} J Ⓓ 8×10^{5} J

Q6 A ball moves with velocity v. If the velocity is **doubled to 2v**, the **kinetic energy** becomes:

ⓐ $KE_f = 2 \cdot KE_i$ Ⓑ $KE_f = 3 \cdot KE_i$ © $KE_f = KE_i$ Ⓓ $KE_f = 4 \cdot KE_i$

Q7 If the **kinetic energy** of an object is **doubled** while its mass stays constant, its **speed** must become:

ⓐ $v_f = \sqrt{2} \cdot v_i$ Ⓑ $v_f = 2 \cdot v_i$ © $v_f = 4 \cdot v_i$ Ⓓ $v_f = \frac{1}{\sqrt{2}} \cdot v_i$

Q8 If the kinetic energy of an object decreases to one-quarter of its initial value ($KE_f = \frac{1}{4}KE_i$) while its mass stays constant, its speed must become:

ⓐ $v_f = \frac{1}{4} \cdot v_i$ Ⓑ $v_f = 4 \cdot v_i$ © $v_f = \frac{1}{2} \cdot v_i$ Ⓓ $v_f = 2 \cdot v_i$

Q9 Cars A and B move along a frictionless track. Car A has half the mass of Car B ($m_A = \frac{1}{2}m_B$) and moves at three times the speed of Car B ($v_A = 3v_B$). Which equation is correct?



ⓐ $KE_A = \frac{3}{2}KE_B$ Ⓑ $KE_A = \frac{9}{2}KE_B$ © $KE_A = \frac{9}{4}KE_B$ Ⓓ $KE_A = 18KE_B$

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Q10 Objects X and Y have equal kinetic energy ($KE_X = KE_Y$). The mass of X is four times the mass of Y ($m_X = 4m_Y$). Which equation is correct for velocity?

ⓐ $v_X = 2v_Y$ Ⓑ $v_X = \frac{1}{4}v_Y$ Ⓒ $v_X = 4v_Y$ Ⓓ $v_X = \frac{1}{2}v_Y$

Q11 Particles A and B have masses such that $m_A = 8m_B$. If the kinetic energy of A is half the kinetic energy of B ($KE_A = \frac{1}{2}KE_B$), and the speed of B is $v_B = 40$ m/s, find the speed of A (v_A).

ⓐ 10 m/s Ⓑ 20 m/s Ⓒ 5 m/s Ⓓ 40 m/s

Q12 Cars A and B travel along a highway. Car A has $\frac{3}{4}$ the mass of Car B ($m_A = \frac{3}{4}m_B$), and Car A moves at $\frac{4}{3}$ the speed of Car B ($v_A = \frac{4}{3}v_B$). If the kinetic energy of Car B is $KE_B = 270$ kJ, calculate the kinetic energy of Car A (KE_A).

ⓐ 270 kJ Ⓑ 480 kJ Ⓒ 360 kJ Ⓓ 202.5 kJ

Q12 A dump truck loaded with sand has an **initial total mass** of **5000 *kg*** and is moving at an **initial speed** of **20.0 *m/s***.
As the truck moves, sand **continuously leaks out**. The truck then moves at a **new speed** of 25.0 m/swhile maintaining the **same kinetic energy** as before.
What is the **mass of sand that leaked out**?



Ⓐ 1800 kg Ⓑ 3200 kg Ⓒ 1000 kg Ⓓ 4000 kg

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Worked Example 5.1 **A net force does +300 J of work on a 5 kg object initially at rest. Find its final velocity.**

1. APPLY THE THEOREM

$$W = \Delta E = KE_{final} - KE_{initial}$$

2. IDENTIFY INITIAL STATE

Since the object starts at rest, $KE_{initial} = 0$.

3. FIND FINAL KE

$$300 = KE_{final} - 0 \rightarrow KE_{final} = 300\,J$$

4. APPLY KE FORMULA

$$KE_final = ½\,m\,v^2 \rightarrow 300 = ½ \times 5 \times v^2$$

5. SOLVE FOR v^2

$$\boldsymbol{v \approx 10.95\ m/s}$$

Practice — Section Review

FR25 An object has an initial KE of 200 J. A resistive force does −80 J of work on it. Find its final KE. *Ans: 120 J*

.....
.....
.....
.....

FR26 A 2 kg object at rest is acted on by a net force that does +64 J of work. Find its final speed. *Ans: 8 m/s*

.....
.....
.....
.....

FR27 A moving object has KE = 500 J. Friction does −500 J of work on it as it comes to rest. Confirm this using the Work–Energy Theorem.

Ans: $\Delta E = -500\,J \rightarrow KE_{final} = 0\,J$ *object stops*

.....
.....

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Work–Energy Theorem

Worked Example 5.1 **A net force does +300 J of work on a 5 kg object initially at rest. Find its final velocity.**

1. APPLY THE THEOREM

$$W = \Delta E = KE_{final} - KE_{initial}$$

2. IDENTIFY INITIAL STATE

Since the object starts at rest, $KE_{initial} = 0$.

3. FIND FINAL KE

$$300 = KE_{final} - 0 \rightarrow KE_{final} = 300\,J$$

4. APPLY KE FORMULA

$$KE_{final} = \tfrac{1}{2} m v^2 \rightarrow 300 = \tfrac{1}{2} \times 5 \times v^2$$

5. SOLVE FOR v^2

$$\boldsymbol{v \approx 10.95\ m/s}$$

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5. Rotational Kinetic Energy

KPI 4

An object does **not have to move** from one location to another to possess **kinetic energy**.

An object can **rotate about an axis** and therefore have **rotational kinetic energy**.

For example, a **spinning wheel** or toy top has **rotational kinetic energy**.



The equation is:

$$KE_{rot} = \frac{1}{2} I\omega^2$$

where:

- K_{rot} = rotational kinetic energy.
- I = moment of inertia.
- ω = angular velocity.

✓ **Important comparison**

Characteristic	Translational Motion	Rotational Motion
Governing Equation	$KE_{trans} = \frac{1}{2}mv^2$	$KE_{rot} = \frac{1}{2}I\omega^2$
Inertial Quantity	Mass (m)	Moment of Inertia (I)
Kinematic Quantity	Linear Speed (v)	Angular Velocity (ω)
Physical Context	Linear / curved displacement	Rotation about an axis

✓ **Quick Check**

Q13 A basketball player spins a basketball on his finger at **3 rad/s**, then spins it at **6 rad/s**. The **rotational kinetic energy** of the basketball will:



ⓐ increase by a factor of 2 Ⓑ increase by a factor of 4

© decrease by a factor of 4 Ⓓ decrease by a factor of 2

Q13 A spinning disc has a moment of inertia of 4 kg · m^2 and rotates with an angular speed of 5 rad/s. Calculate its rotational kinetic energy.

ⓐ 20 J Ⓑ 50 J © 100 J Ⓓ 200 J

Q13 A point mass of 2 kg is attached to a light cord of length 0.5 m rotating in a horizontal circle at an angular speed of 4 rad/s. Calculate its rotational kinetic energy. (Hint: $I = mr^2$)

ⓐ 2 J Ⓑ 4 J © 8 J Ⓓ 16 J

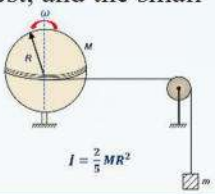
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Q13 A solid uniform sphere of **mass** M and **radius** R can rotate about a **fixed vertical axis** attached to the sphere through a small ball of mass m. At an instant, the sphere is released from rest, and the small mass falls vertically, causing the sphere to rotate about its axis.

The sphere has a **moment of inertia** equal to $I = \frac{2}{5}MR^2$ and an **angular velocity** ω.

What is the correct expression for the rotational kinetic energy KE_{rot}**?**

Ⓐ $MR^2\omega^2$ Ⓑ $\frac{1}{2}MR^2\omega^2$ Ⓒ $\frac{2}{5}MR^2\omega^2$ Ⓓ $\frac{1}{5}MR^2\omega^2$



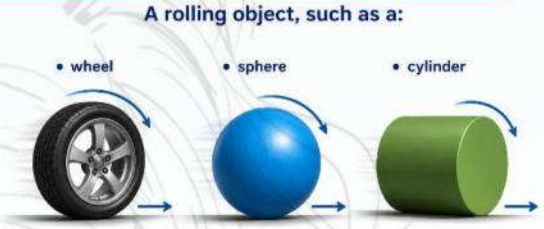
6. Rolling Objects

KPI 5 AND KPI 6

A rolling object, such as a:

- wheel,
- sphere,
- cylinder,

can have **both translational and rotational kinetic energy** at the same time.



Therefore:

$$KE_{total} = KE_{trans} + KE_{rot}$$

$$KE_{total} = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2$$

For an object rolling without slipping:

$$v = \omega r \Leftrightarrow \omega = \frac{v}{r}$$

✓ Key idea

A rolling wheel is doing **two things simultaneously**: **Translating + Rotating**

so both forms of kinetic energy must be considered.



For Deeper Understanding A diver leaping from a diving board is a good real-life example:

her **center of mass** moves through the air, so she has **translational kinetic energy**,

and her body **rotates** about that center of mass, so she also has **rotational kinetic energy**.

Just before she slices into the water in a straight dive, most of her energy has become **translational**



✓ Quick Check

Q14 When a car **wheel rolls down** over a hill, which of the following statements is true?

Ⓐ The wheel will have rotational kinetic energy only.

Ⓑ The wheel will not have any type of kinetic energy.

Ⓒ The wheel will have translational kinetic energy only.

Ⓓ The wheel will have both rotational and translational kinetic energies.



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The figure shows that the diver has two types of kinetic energy while jumping from the diving board:

1. Translational Kinetic Energy

- The diver's **center of mass** moves from one position to another.
- So, the diver has **translational kinetic energy**:

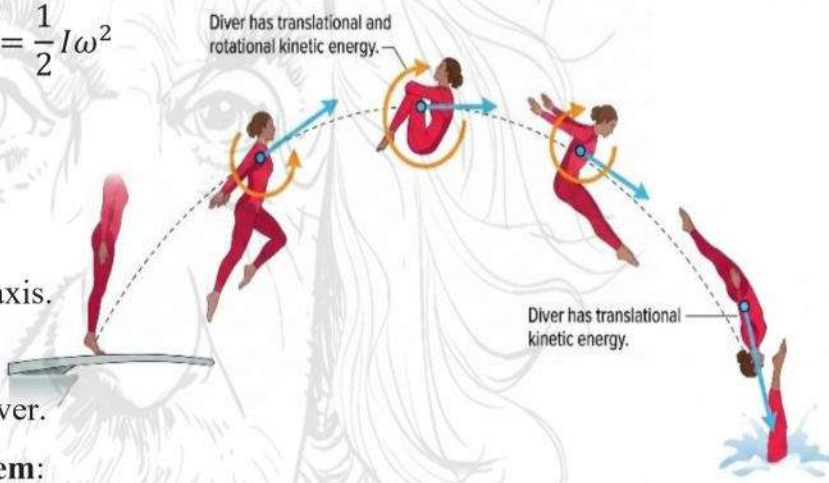
$$K_{\text{trans}} = \frac{1}{2}mv^2$$

- **Translation** = the whole body moves from one place to another.

2. Rotational Kinetic Energy

- At the same time, the diver **rotates** about her center of mass.
- Therefore, she also has **rotational kinetic energy**:

$$K_{\text{rot}} = \frac{1}{2}I\omega^2$$



- **Where:**
  - ✓ I = **moment of inertia**
  - ✓ ω = **angular velocity**
- **Rotation** = the body spins around an axis.

3. What does the diving board do?

- The diving board does **work** on the diver.
- According to the **work–energy theorem**:

$$W_{\text{net}} = \Delta KE$$

- So, the work done by the diving board **increases the diver's kinetic energy**.

4. When she enters the water

- When the diver enters the water, her motion is **mainly translational**.
- So, she has **mostly translational kinetic energy**.

In one sentence:

The diving board transfers energy to the diver, giving her **translational kinetic energy** because her center of mass moves, and **rotational kinetic energy** because she rotates about her center of mass.

Q14 While a diver is in the air performing a dive (somersaulting) after leaping from a diving board, which type(s) of kinetic energy does she possess?

ⓐ Translational kinetic energy only
Ⓑ Rotational kinetic energy only
© Both translational and rotational kinetic energies
Ⓓ Elastic potential energy only



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7. Potential Energy

KPI 7

Energy does not always come from motion.

Energy can also be **stored in a system** because of interactions between objects or because of the system's configuration.

This stored energy is called: **Potential Energy (PE)**

For example, rocks high on a mountain have stored energy because of their interaction with Earth through gravity.

✓ Quick Check

Which of the following is defined as "the energy stored in the configuration of a system of objects that exert forces on one another"?

ⓐ Potential energy Ⓑ Kinetic energy Ⓒ Thermal energy Ⓓ Chemical energy

8. Gravitational Potential Energy

KPI 8 AND KPI 9



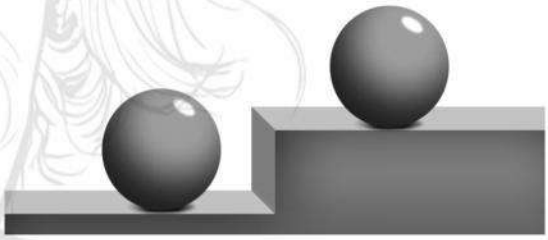
When considering gravitational potential energy, the system is usually **Object + Earth**

The gravitational interaction between the object and Earth stores energy when the object is moved away from Earth.

This energy is called: **Gravitational Potential Energy (GPE)**

The equation is:

$$GPE = mgh$$



where:

- m = mass of the object, in kg.
- g = gravitational field strength, approximately 9.8 m/s^2.
- h = height above the reference level, in m.

Notes on Proportionality

- GPE is directly proportional to mass: if mass doubles, GPE doubles.
- GPE is directly proportional to height: if height doubles, GPE doubles; if height triples, GPE triples.

Zayed lifts a decorative vase vertically inside a building. Initially, the vase is at a height of **3.0** mabove the ground, where the ground is the reference level, and the vase–Earth system has a gravitational potential energy of **90** J.

If Zayed lifts the vase to a height of 12.0 m**, what is its new gravitational potential energy** (GPE_2)**?**

Ⓐ 360 J Ⓑ 270 J Ⓒ 1440 J Ⓓ 180 J

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Ahmed places a book at an **initial height** of $\mathbf{h_1 = 20}$ cm above the ground, where the book–Earth system possesses a **gravitational potential energy** of $\mathbf{GPE_1 = 120}$ J.

At what **new height** $(\mathbf{h_2})$ above the ground would the book have a **gravitational potential energy** of $\mathbf{GPE_2 = 480}$ J?

Ⓐ 80 cm Ⓑ 40 cm Ⓒ 60 cm Ⓓ 320 cm

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Worked Example

Gravitational Potential Energy

A student places a **2.0-kg physics textbook** on a high shelf that is **1.5 m** above the classroom floor. Calculate the **gravitational potential energy (GPE)** of the book relative to the floor.

(Use $g = 9.81$ m/s^2).

Solution:

GIVEN:

Mass (m) = 2.0 kg Height (h) = 1.5 m Gravity (g) = 9.81 m/s^2

RELATIONSHIP:

$$GPE = mgh$$

$$GPE = (2.0)(9.81)(1.5) = 29.43 \text{ J}$$

9. The Reference Level

The **height** (h) must be measured relative to a chosen **reference level**.

The **reference level** is the position where:

$$h = 0 \quad \text{and therefore} \quad GPE = 0$$

*(Note: The reference level can be chosen at any **convenient height** depending on the problem).*



1. Above the reference level:

Since the height is positive ($h > 0$), the gravitational potential energy is **positive**:$GPE > 0$

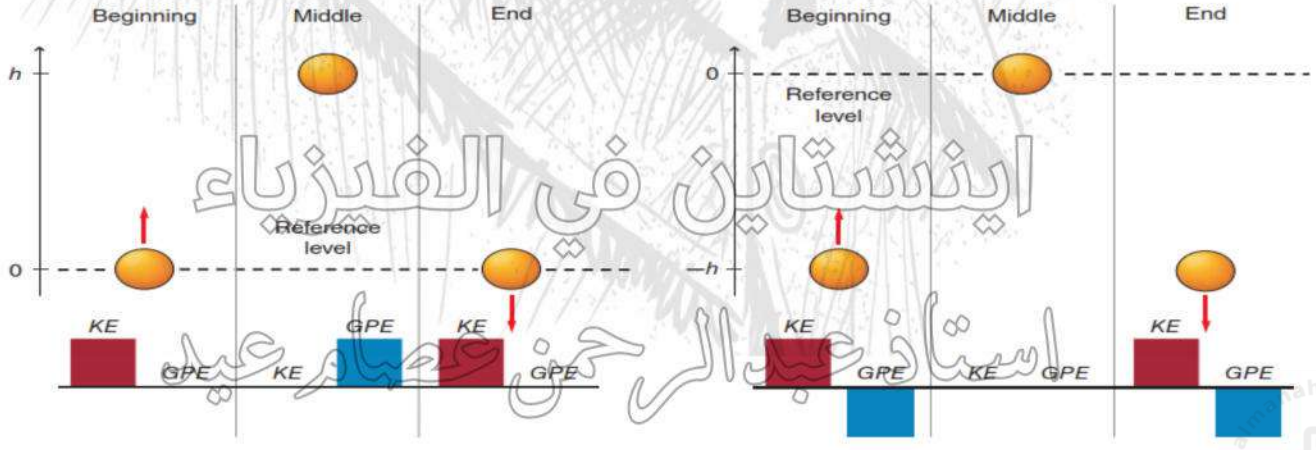
2. Below the reference level:

Since the height is negative ($h < 0$), the gravitational potential energy is **negative**:$GPE < 0$

While the numerical value of GPE depends on the chosen reference level, the difference ΔGPE between any two elevations is strictly invariant.***Δ GPE***

This is why **different reference levels** can be used to solve the same physical problem.

Reference Level: *The point where GPE = 0. It can be chosen at any convenient height.*



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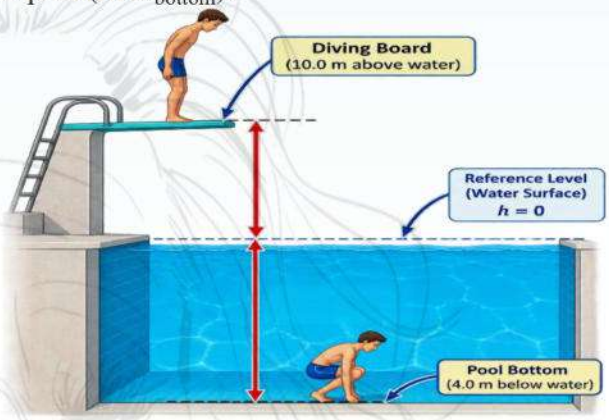
A diver of **mass m**stands on a diving board located **10.0** mabove the water surface of a swimming pool.

The bottom of the pool is **4.0** mbelow the water surface.

If the **water surface is selected as the reference level (h = 0)**.

Which row in the table correctly identifies the sign and magnitude of the diver's **gravitational potential energy** on the diving board ($\mathbf{GPE}_{board}$) and at the bottom of the pool ($\mathbf{GPE}_{bottom}$)?

	GPEboard	GPEbottom
Ⓐ	$+10.0\,mg$	$-4.0\,mg$
Ⓑ	$+10.0\,mg$	$+4.0\,mg$
Ⓒ	$+14.0\,mg$	0
Ⓓ	$+6.0\,mg$	$-4.0\,mg$



10. Work Done by Gravity

KPI 10 AND KPI 11

Suppose an object moves vertically from an initial height h_i to a final height h_f.

The work done by gravity is:

$$W_g = mg(h_i - h_f)$$

The change in gravitational potential energy is:

$$\Delta\text{GPE} = \text{GPE}_f - \text{GPE}_i = mg(h_f - h_i)$$

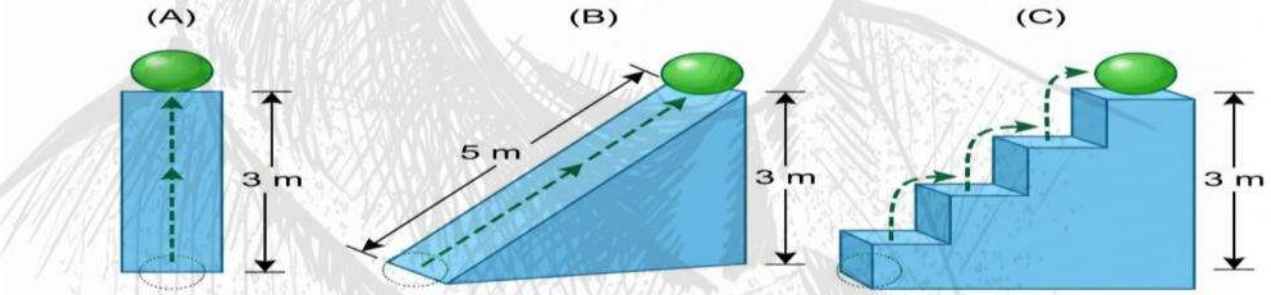
and:

$$W_g = -\Delta\text{GPE}$$

This relationship is extremely important:

Work Done by Gravity = −(Change in Gravitational Potential Energy)

For Deeper Understanding — Because $W_g = mg(h_i - h_f)$ depends only on the **height difference**, the **work done against gravity** between two points is the **same no matter which path** is taken to get there straight up, or by any longer, winding route.



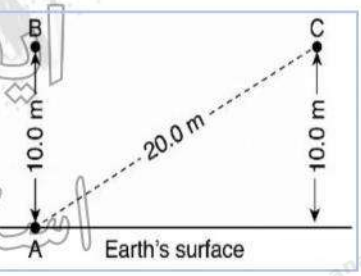
In each case, the same amount of work is being done.

✓ **Quick Check**

Q15 The diagram below shows points A, B, and C at or near Earth's surface. A mass is moved from A to B, and **100 J of work is done against gravity**.

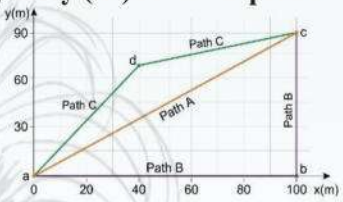
What is the amount of work done against gravity as an identical mass is moved from A to C? *(Assuming B and C are at the same height).*

ⓐ 100 J Ⓑ 173 J Ⓒ 200 J Ⓓ 273 J



Q15 A **15.0 kg object** is moved upward under the gravitational force from **position A** to **position C**, through **three different paths** (Path A, Path B, and Path C) as shown in the figure.
Which of the following is correct regarding the work done against gravity (W) for each path?

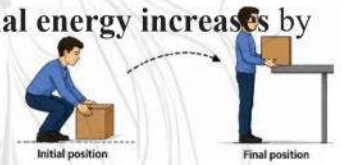
ⓐ $(W)_{ac} = (W)_{abc} = (W)_{adc}$
Ⓑ $(W)_{ac} < [(W)_{abc} = (W)_{adc}]$
© $[(W)_{ac} + (W)_{abc}] = (W)_{adc}$
Ⓓ $(W)_{ac} = [(W)_{abc} - (W)_{adc}]$



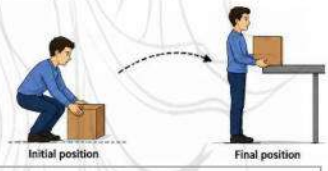
Work Done by Gravity

- Moving Up: gravity opposes the motion → $Wg = -mgh$
- Moving Down: gravity assists the motion → $Wg = +mgh$

A student lifts a box **vertically upward**. The box has a weight of 200 N and is raised through a height of 3 m. During the lift, its **gravitational potential energy increases** by 600 J.
What is the **work done by the force of gravity** on the box?
ⓐ +600 J ⓑ −600 J © +200 J Ⓓ −200 J



A student lifts a heavy box vertically upward from the floor to a shelf at a constant speed.
Which row in the table below **correctly**?

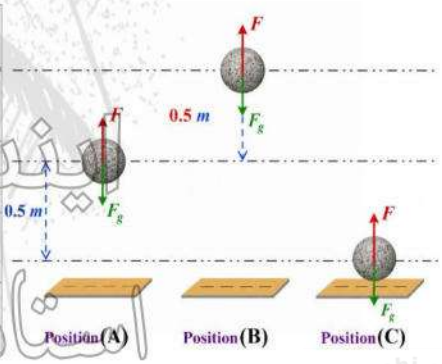


	Work done by Gravity (Wg)	Work done by Student	Change in GPE (ΔGPE)
ⓐ	Positive (+)	Negative (-)	Decreases
Ⓑ	Negative (-)	Zero (0)	Increases
©	Negative (-)	Positive (+)	Increases
Ⓓ	Zero (0)	Positive (+)	Constant

A weightlifter is lifting a marble ball of **mass m**from **position (A)** located above the ground to **position (B)**, then leaves it to fall back to the ground at **position (C)** as shown in the figure.

Which of the table rows is correct in terms of the **work done on the ball** and the **gravitational potential energy stored in it** at each of the three positions?

	Position (A)	Position (B)	Position (C)
Ⓐ	$W_g = (+0.5\ \text{m}) \times F_g$	$W_g = (+0.5\ \text{m}) \times F_g$	$W_g = 0$
Ⓑ	$U_g = (+0.5\ \text{m}) \times F_g$	$U_g = (+1.0\ \text{m}) \times F_g$	$U_g = 0$
©	$W_g = (+0.5\ \text{m}) \times F_g$	$W_g = (-0.5\ \text{m}) \times F_g$	$W_g = (-1.0\ \text{m}) \times F_g$
Ⓓ	$U_g = (-0.5\ \text{m}) \times F_g$	$U_g = (+1.0\ \text{m}) \times F_g$	$U_g = (1.0\ \text{m}) \times F_g$



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A warehouse worker lifts a crate of **mass 15.0** kg vertically at a **constant speed** from the floor to a storage shelf located **2.40** m above the floor. Taking the **floor as the reference level** ($h = 0$) and $\mathbf{g = 9.80}$ m/s^2, what is the **gravitational potential energy** (**GPE**) of the crate on the shelf?

Ⓐ 36.0 J Ⓑ 147 J Ⓒ 353 J Ⓓ 706 J

An eagle of **mass 4.50** kg glides downward from an **initial altitude** of **180** m above the ground to a tree branch at a **final altitude** of **45.0** m.

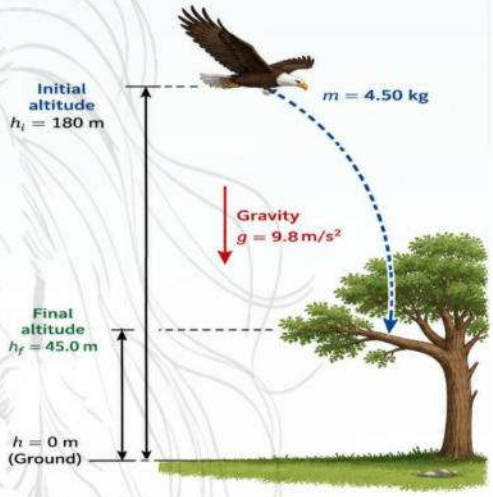
What are the **change in gravitational potential energy** (**ΔGPE**) and the **work done by gravity** ($\mathbf{W_g}$)? (Use $\mathbf{g = 9.8}$ m/s^2)

Ⓐ $\Delta\text{GPE} = -5.95 \times 10^3$ J , $W_g = +5.95 \times 10^3$ J

Ⓑ $\Delta GPE = +5.95 \times 10^3$ J , $W_g = -5.95 \times 10^3$ J

Ⓒ $\Delta GPE = -7.94 \times 10^3$ J , $W_g = +7.94 \times 10^3$ J

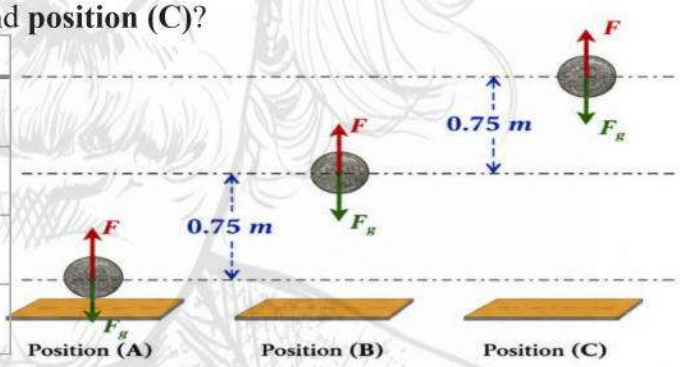
Ⓓ $\Delta GPE = -1.98 \times 10^3$ J , $W_g = -1.98 \times 10^3$ J



A weightlifter lifts a marble ball of **mass m** from **position (A)** on the ground to **position (B)**, then to **position (C)** as shown in the figure.

Which of the table rows is correct in terms of the **work done on the ball** and the **gravitational potential energy stored in it** at **position (A)** and **position (C)**?

	Position (A)	Position (C)
Ⓐ	$W_g = 0$	$W_g = (+1.50\text{ m}) \times F_g$
Ⓑ	$U_g = 0$	$U_g = (+1.50\text{ m}) \times F_g$
Ⓒ	$W_g = 0$	$W_g = (+0.75\text{ m}) \times F_g$
Ⓓ	$U_g = 0$	$U_g = (-1.50\text{ m}) \times F_g$



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A crate of **mass 10** kg is lifted vertically upward by a rope at a **constant speed** from an **initial height** of **7** m above the ground to a **final height** of **16** m. Taking the acceleration due to gravity as $\mathbf{g = 9.81}$ m/s^2, calculate:

Part A: The **change in gravitational potential energy (ΔPE)** of the crate resulting from the lift.

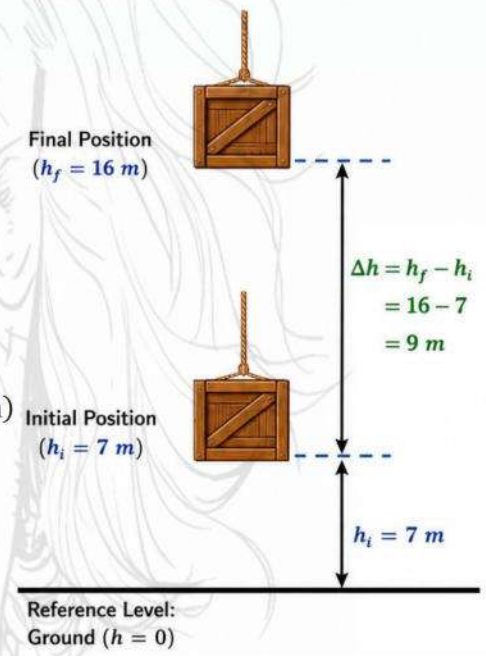
Part B: The **work done by the gravitational force (W_g)** during the lift.

Part C: The **work done by the tension force** in the rope **(W_T)** to lift the crate.

Given: $m = 10$ kg, $h_i = 7$ m, $h_f = 16$ m, $g = 9.81$ m/s^2, $v =$ constant

Required

Required: **ΔPE** =?, $\mathbf{W_g}$ =?, $\mathbf{W_T}$ =?



Step-by-Step Solution

Part A: Change in Gravitational Potential Energy (ΔPE)

1. **Determine the vertical displacement (Δh):**

$$\mathbf{\Delta h} = h_f - h_i = 16\text{ m} - 7\text{ m} = \mathbf{9}\text{ m}$$

2. **Apply the potential energy formula:**

$$\mathbf{\Delta PE = mg\Delta h}$$

$$\Delta PE = (10\text{ kg}) \times \left(9.81\text{ m/s}^2\right) \times (16\text{ m} - 7\text{ m})$$

$$\Delta PE = 10 \times 9.81 \times 9 = \mathbf{882.9}\text{ J}$$

Part B: Work Done by Gravity (W_g)

1. **Apply the work–potential energy theorem:**

$$\mathbf{W_g = -\Delta PE}$$

2. **Substitute ΔPE from Part A:**

$$\mathbf{W_g = -882.9}\text{ J}$$

(Physical Meaning: Gravity acts downward while the displacement is upward, resulting in negative work that stores energy into the gravitational field).

Part C: Work Done by Tension (W_T)

1. **Apply the Work–Energy Theorem:**

$$\mathbf{W_{total} = \Delta KE}$$

2. **Account for the constant speed condition:**

$$v = \text{constant} \Rightarrow \mathbf{\Delta KE = 0} \Rightarrow \mathbf{W_{total} = 0}$$

3. **Calculate tension work (W_T):**

$$\mathbf{W_{total} = W_g + W_T = 0}$$

$$-882.9\text{ J} + W_T = 0 \Rightarrow \mathbf{W_T = +882.9}\text{ J}$$

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You lift a **7.30**-kg **bowling ball** from a storage rack and hold it up to your shoulder. The **storage rack** is **0.610** m above the floor, and your **shoulder** is **1.12** m above the floor. Taking $\mathbf{g = 9.8}$ N/kg (or $\mathbf{9.8}$ m/s^2):

Part a: When the bowling ball is at your shoulder, what is the ball–Earth system's **gravitational potential energy relative to the floor**?

Part b: When the bowling ball is at your shoulder, what is the ball–Earth system's **gravitational potential energy relative to the rack**?

Part c: How much **work was done by gravity** ($\mathbf{W_g}$) as you lifted the ball from the rack to shoulder level?

Given: $m = 7.30$ kg, $h_r = 0.610$ m, $h_s = 1.12$ m, $g = 9.8$ N/kg

Required

Required: $\mathbf{GPE_{s\ rel\ f}} = ?$, $\mathbf{GPE_{s\ rel\ r}} = ?$, $\mathbf{W_g} = ?$

Step-by-Step Solution

Part a: Gravitational Potential Energy Relative to the Floor

1. **Set the reference level at the floor ($\mathbf{h = 0}$):**

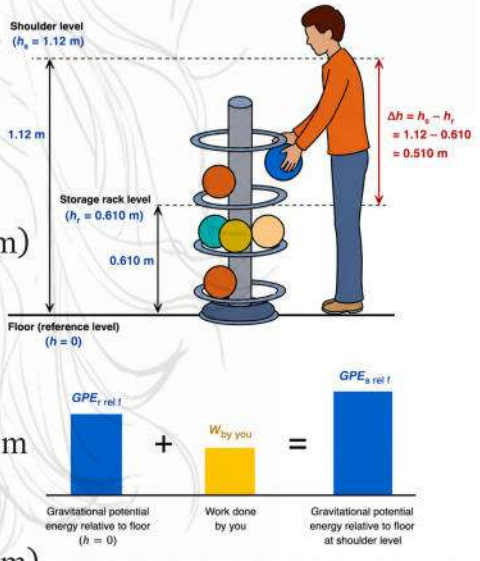
The ball at shoulder level is at height $h_s = 1.12$ m.

2. **Apply the potential energy equation:**

$$\mathbf{GPE_{s\ rel\ f} = mgh_s}$$

$$GPE_{s\ rel\ f} = (7.30\ \text{kg}) \times (9.8\ \text{N/kg}) \times (1.12\ \text{m})$$

$$\mathbf{GPE_{s\ rel\ f} = 80.1\ J \approx 8.0 \times 10^1\ J}$$



Part b: Gravitational Potential Energy Relative to the Rack

1. **Set the reference level at the rack height ($\mathbf{h_{rack} = 0}$):**

Determine the height of the shoulder relative to the rack:

$$\mathbf{h = h_s - h_r} = 1.12\ \text{m} - 0.610\ \text{m} = \mathbf{0.510}\ \text{m}$$

2. **Calculate the potential energy relative to the rack:**

$$\mathbf{GPE_{s\ rel\ r} = mg(h_s - h_r)}$$

$$GPE_{s\ rel\ r} = (7.30\ \text{kg}) \times (9.8\ \text{N/kg}) \times (0.510\ \text{m})$$

$$\mathbf{GPE_{s\ rel\ r} = 36.48\ J \approx 36\ J}$$

*(**Note:** This is also equal to the work done by you to lift the ball at constant speed).*

Part c: Work Done by Gravity ($\mathbf{W_g}$)

1. **Apply the gravitational work equation:**

The downward force of gravity opposes the upward displacement:

$$\mathbf{W_g = -F_g \Delta h = -(mg)(h_s - h_r)}$$

2. **Substitute and calculate:**

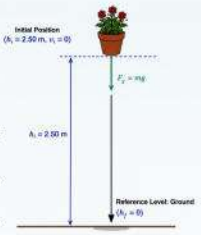
$$W_g = -(7.30\ \text{kg}) \times (9.8\ \text{N/kg}) \times (1.12\ \text{m} - 0.610\ \text{m})$$

$$\mathbf{W_g = -36\ J}$$

*(**Note:** The work done by gravity is negative because the weight force acts downward, opposite to the upward lifting displacement).*

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A flowerpot of **mass 800** g falls from rest from an **initial height** of **250** cm above the ground. Taking the acceleration due to gravity as $\mathbf{g = 9.81}$ m/s^2,calculate the **work done by the gravitational force** ($\mathbf{W_g}$) on the flowerpot as it falls to the ground.



If a **1.8**-kg brick falls to the ground from a chimney that is **6.7** m high, what is the **change in the potential energy** (**ΔPE**) of the brick–Earth system?

A **25.0-kg shell** is shot from a cannon at **Earth's surface**. The **reference level** is Earth's surface.

a. What is the **gravitational potential energy** of the **shell–Earth system** when the shell's height is **425 m**?

b. What is the **change in the system's gravitational potential energy** when the shell falls to a height of **225 m**?

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✓ **Very important Einstein's Exam (by Mr. Abdelrahman Esam):**

To quickly solve "Conservation of Energy" problems and easily eliminate wrong choices in MCQs, lock these four relationships into your mind:



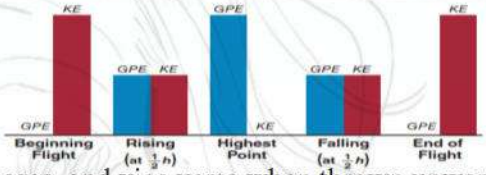
1. Direct Relationships (Based on the Equations)

- **Kinetic Energy (KE) and Speed (v): Direct relationship.**

  (As the object moves faster, its kinetic energy increases).

- **Potential Energy (PE) and Height (h): Direct relationship.**

- (As the object gets higher above the reference level, its potential energy increases).



2. Inverse Relationships (During Motion / Free Fall)

- **Height (h) and Speed (v): Inverse relationship.**

(As an object falls, its height decreases while its speed increases, and vice versa when thrown upward).

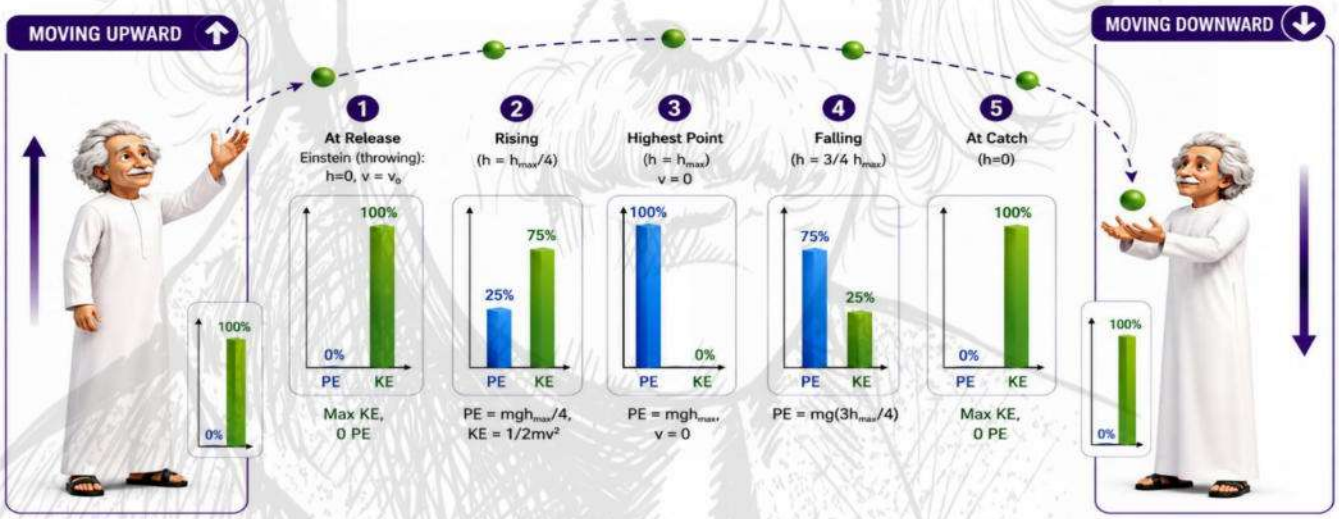
- **Potential Energy (PE) and Kinetic Energy (KE): Inverse relationship.**

(Whatever the object loses in potential energy, it gains in kinetic energy, keeping the total mechanical energy constant).

Einstein's Bottom Line:

"At the **highest point**, an object has **maximum** PE **and minimum** KE.
At the **lowest point** (reference level), it has **minimum** PE **and maximum** KE."

Energy Transformation Note



- Moving upward → Potential Energy increases while Kinetic Energy decreases.
- Moving downward → Potential Energy decreases while Kinetic Energy increases.

A ball is thrown **vertically upward** in the air (ignoring air resistance).
As the ball rises towards its highest point,
which of the following statements is **completely correct**?

ⓐ Its **kinetic energy decreases**, and its total mechanical energy decreases.

Ⓑ Its **gravitational potential energy increases**, and gravity does positive work on it.

© Its **kinetic energy decreases**, and gravity does **negative work** on it.

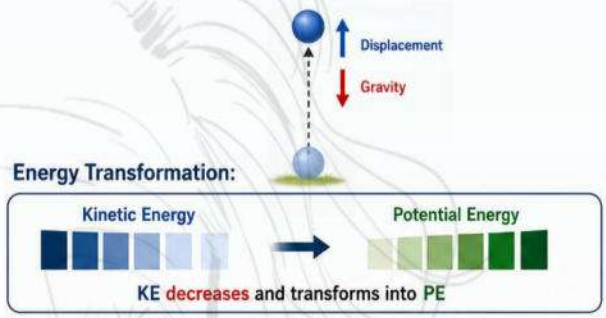
Ⓓ Its **total mechanical energy remains constant**, and its velocity increases.

11. Upward and Downward Motion

KPI 12

Object moving upward ↑

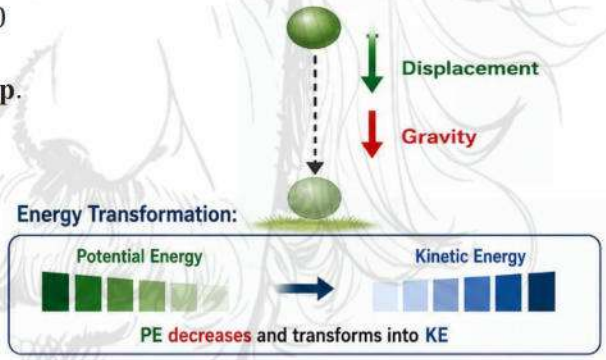
- **Force vs. Displacement:** The displacement is upward, while gravity acts downward (**opposite** directions).
- **Work Done:** Gravity does **negative work** $W_g < 0$
- **Energy Changes:** As the object rises, it **slows down**.
  - ✓ Kinetic Energy decreases: $KE \downarrow$
  - ✓ Potential Energy increases: $GPE \uparrow$



Energy Transformation: $KE \rightarrow GPE$

Object moving downward ↓

- **Force vs. Displacement:** The displacement and gravitational force are **both downward** (same direction).
- **Work Done:** Gravity does **positive work** $W_g > 0$
- **Energy Changes:** As the object falls, it **speeds up**.
  - ✓ Kinetic Energy increases: $KE \uparrow$
  - ✓ Potential Energy decreases: $GPE \downarrow$
- **Energy Transformation:**
- $GPE \rightarrow KE$



Direction is important!

✓ When an object moves **against** the direction of gravity, the object **loses** kinetic energy ($W < 0$).

✓ When it moves **in the direction** of gravity, the object **gains** kinetic energy ($W > 0$).

Which statement is correct regarding the relationship between the **direction of motion** and the **kinetic energy (KE)** of an object moving in Earth's gravitational field?



ⓐ Moving against gravity increases KE, while moving with gravity decreases KE.

Ⓑ Moving against gravity does positive work, while moving with gravity does negative work.

© Moving **against gravity** causes the object to **lose** KE, while moving **in the direction of gravity** causes it to **gain** KE.

Ⓓ The direction of motion has no effect on whether the object gains or loses KE.

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An apple falls from a high tree branch towards the ground (ignoring air resistance).

As the apple falls, which of the following statements is **completely correct**?

ⓐ Its **kinetic energy increases**, and its total mechanical energy increases.

Ⓑ Its **gravitational potential energy decreases**, and gravity does negative work on it.

© Its **total mechanical energy remains constant**, and its kinetic energy decreases.

Ⓓ Its **gravitational potential energy decreases**, and gravity does **positive work** on it.

Earth's gravity may exert **positive or negative work**, or it may **not exert work** on a body placed within its influence. If Earth's gravity exerts **negative work** on the body, **what is the body's movement relative to the Earth, and what happens to its kinetic energy?**

ⓐ Moving **upward**, the kinetic energy **increases**.

Ⓑ Moving **upward**, the kinetic energy **decreases**.

© Moving **downward**, the kinetic energy **increases**.

Ⓓ Moving **downward**, the kinetic energy **decreases**.

If Earth's gravity does **positive work** on a body, **what is the direction of the body's motion relative to the Earth, and what happens to its kinetic energy?**

ⓐ Moving **upward**, the kinetic energy **increases**.

Ⓑ Moving **upward**, the kinetic energy **decreases**.

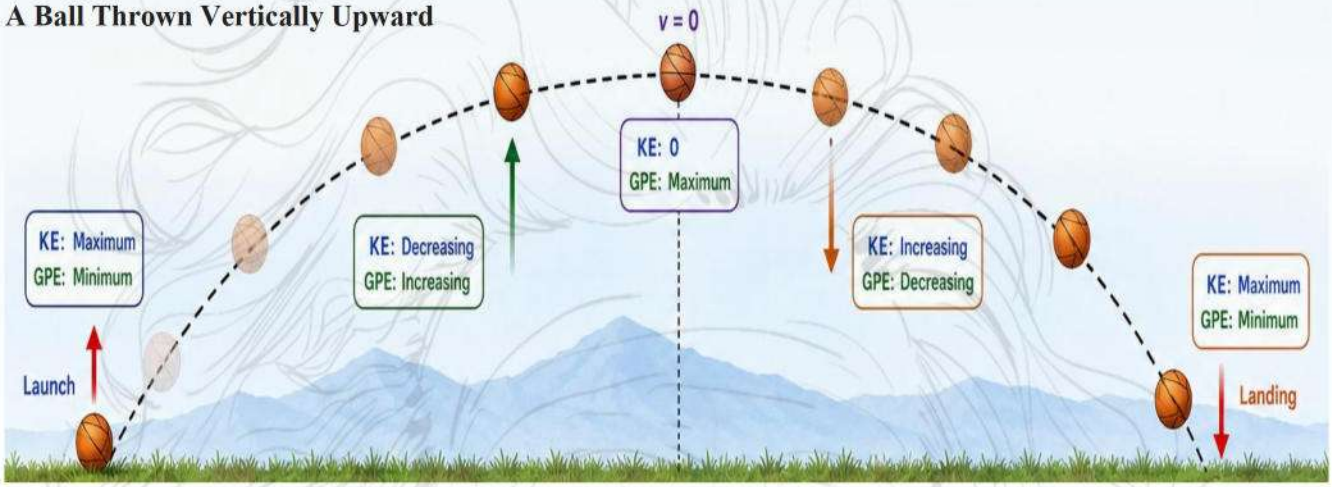
© Moving **downward**, the kinetic energy **increases**.

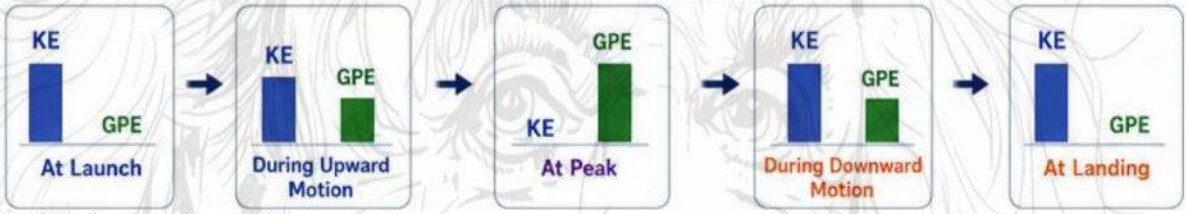
Ⓓ Moving **downward**, the kinetic energy **decreases**.

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12. Energy Transformation During Vertical Motion

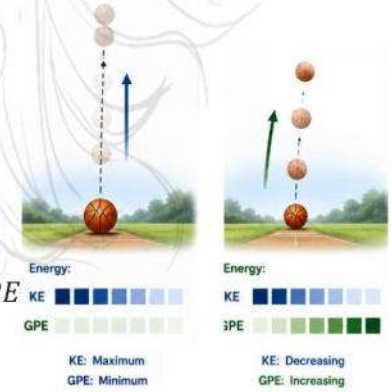
A Ball Thrown Vertically Upward





1. At the Beginning (Launch):

- The ball has significant kinetic energy.
- KE **is at its maximum**.

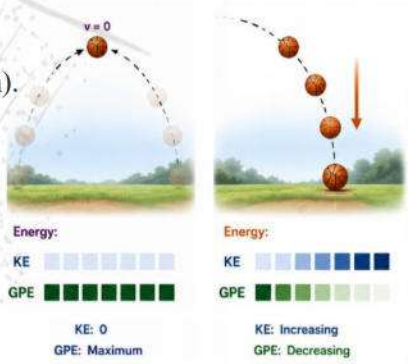


2. During Upward Motion:

- The ball slows down.
- Kinetic energy is transformed into gravitational potential energy: $KE \rightarrow GPE$

3. At the Highest Point (Peak):

- The instantaneous velocity is zero: $v = 0$
- Therefore, kinetic energy is zero: $KE = 0$
- The energy is entirely **gravitational potential energy** (GPE is at its maximum).



4. During the Downward Motion:

- The ball speeds up.
- Gravitational potential energy changes back into kinetic energy:$GPE \rightarrow KE$

The Golden Rule (Conservation of Energy):

If no external work is done on the system (like air resistance),

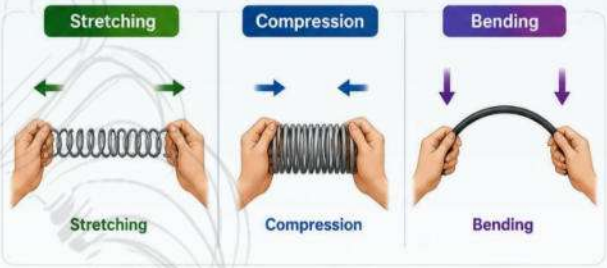
the **total mechanical energy** ($ME = KE + GPE$) remains **constant** throughout the entire flight.

Consider a ball thrown vertically upward.

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13. Elastic Potential Energy

KPI 13



Energy can also be stored when an object changes its shape.

This stored energy is called: **Elastic Potential Energy**

It can result from:

- stretching,
- compression,
- bending.

Examples

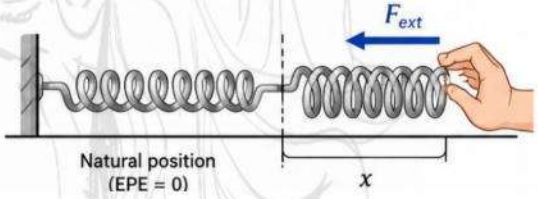
Spring: A compressed or stretched spring stores elastic potential energy.

Elastic Potential Energy (EPE)

When the spring is in its natural position, it is neither stretched nor compressed.

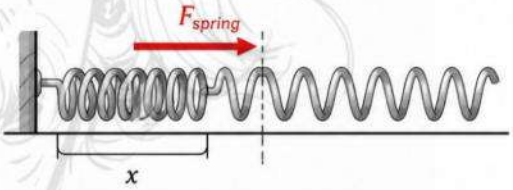
Therefore, its elastic potential energy is: $EPE = 0$

Case 1: Compressing or Stretching the Spring



- An external force does **positive work on the spring**.
- The work is stored as **EPE** $EPE \uparrow$.

Case 2: Returning the Spring to Its Natural Position



- The spring force does **negative work on the spring**.
- The spring's EPE decreases $EPE \downarrow$.
- The released EPE is converted into kinetic energy.

Three Possible Changes in Potential Energy

There are three possible changes in potential energy:

① Increase in Potential Energy $\Delta PE = +$

This means the potential energy **increases** due to an **external force** or **work done on the object**.

② Decrease in Potential Energy $\Delta PE = -$

This means the potential energy **decreases**, and this decrease is converted into an **increase in kinetic energy**.

③ No Change in Potential Energy $\Delta PE = 0$

This means there is **no change in the stored potential energy**.

Fiberglass pole: A pole bends and stores elastic potential energy.

When it straightens, this energy can transform into kinetic energy and gravitational potential energy.

Other examples include rubber bands, trampolines, elastic materials.

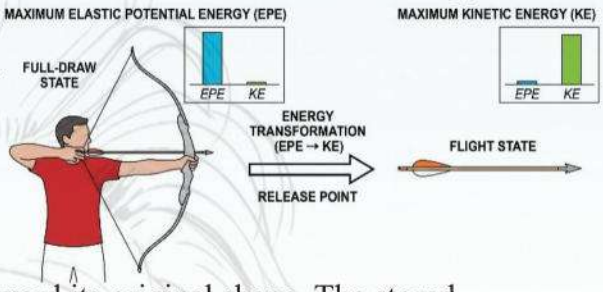
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1. Bow and Arrow

Step 1: The bow is pulled back

When the archer pulls the string back, the bow bends. **Work** is done on the bow, so energy is stored in it as **elastic potential energy**.

Work → EPE



At this point:

- ✓ **EPE = maximum**
- ✓ **KE ≈ 0** for the arrow

Step 2: The string is released

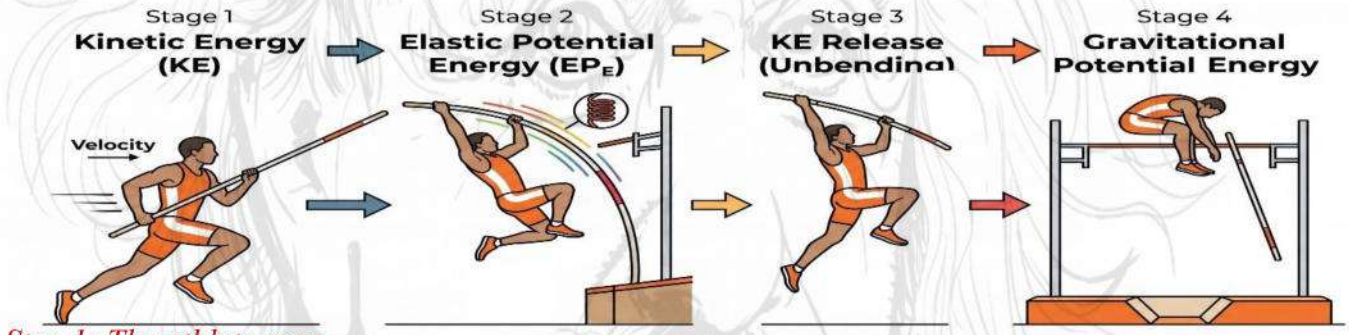
When the archer releases the string, the bow returns toward its original shape. The stored **elastic potential energy** is converted into the arrow's **kinetic energy**.

EPE → KE

Therefore: **EPE decreases → KE increases**

2. Pole Vault

The pole-vault example involves several energy transformations.



Step 1: The athlete runs

The athlete is moving, so she has **kinetic energy** (KE).

Step 2: The pole bends

When the athlete plants the pole into the ground, the flexible pole bends. Some of the athlete's **kinetic energy** is transferred to the pole and stored as **elastic potential energy**.

KE → EPE

Therefore:

- ✓ **KE decreases → EPE increases**
- ✓ When the pole is highly bent: **EPE = maximum**

Step 3: The pole straightens

The pole then returns toward its original shape. The stored **elastic potential energy** is released and converted into **kinetic energy**.

EPE → KE

This helps the athlete move upward.

Step 4: The athlete rises

As the athlete moves higher, her **kinetic energy** is transformed into **gravitational potential energy** (GPE).

KE → GPE

The gravitational potential energy is: $GPE = mgh$

So, the **higher** the athlete rises, the **greater** her gravitational potential energy.

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An archer pulls a bowstring back to its maximum position and holds it **completely still** just before releasing the arrow.

Which statement correctly describes the energy in the system?

ⓐ The system has **kinetic energy only**, because the archer is holding the bowstring.

Ⓑ The system has **elastic potential energy only**, while the arrow has zero kinetic energy.

© The system has **both kinetic energy and elastic potential energy** because the bowstring is stretched.

Ⓓ The system has **neither kinetic energy nor elastic potential energy** because the system is stationary.

A gymnast lands on a trampoline and pushes it downward, causing it to stretch to its **lowest point**. During this downward stretch, how does the trampoline's **elastic potential energy (EPE)** change?



ⓐ It **increases**, because the gymnast's force does positive work on the trampoline.

Ⓑ It **decreases**, because the stored energy is converted into the gymnast's kinetic energy.

© It **remains constant**, because mechanical energy is conserved.

Ⓓ It **decreases**, because the trampoline's restoring force does negative work.

A student stretches a spring to its **maximum extension** and holds it stationary. The student then releases the spring, allowing it to accelerate back toward its **equilibrium (natural) position**.



Which statement **correctly**?

ⓐ The spring's **EPE decreases**, and the spring force does **negative work**.

Ⓑ The spring force does **positive work**, and the spring's **EPE increases** as the spring moves faster.

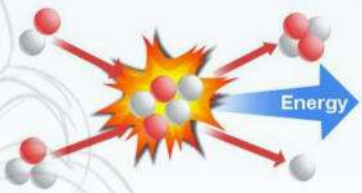
© The spring force does **positive work**, the spring's **EPE decreases**, and the stored energy is converted into **kinetic energy (KE)**.

Ⓓ The spring's **EPE increases**, and the spring force does **negative work** to slow the spring down.

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14. Mass as Energy — Rest Energy

KPI 14



Einstein demonstrated that **mass itself represents energy**.
This energy is called **rest energy**:

$$E_0 = mc^2$$

where:

- E_0 = rest energy(J). m = Rest mass (kg) $c = 3.00 \times 10^8$ m/s (Speed of light)

even a very small amount of mass corresponds to a **huge amount of energy**.

Example — Rest Energy of 1 Gram of Mass



Using Einstein's mass– Rest Energy, $E_0 = mc^2$ For a mass of 1 g

Taking the speed of light as: $c = 3.0 \times 10^8$ m/s

$m = 1\,\text{g} = 1.0 \times 10^{-3}$ kg

$E_0 = (1.0 \times 10^{-3})(3.0 \times 10^8)^2 = 9.0 \times 10^{13}$ J

15. Other Forms of Energy

KPI 15

Energy exists in many different forms.

For Deeper Understanding: The "Flavors" of Energy

Think about how many forms of energy you rely on every day:

- ✓ **Gasoline** provides the chemical energy to run a car.
- ✓ **Food** provides the chemical energy your body uses to move and stay warm.
- ✓ **Power Plants** harness the energy of wind, falling water, fossil fuels, or atoms and transform it into electrical energy for your home.

15.1 Chemical Energy

- **Definition:** Energy stored in chemical bonds.
- **Examples:** Gasoline, fossil fuels, food, and batteries.
- **Transformation:** When gasoline burns or food is digested, chemical energy is released and transformed into other forms.

15.2 Nuclear Energy

- **Definition:** Energy associated with the structure of atomic nuclei. It can be released when the structure of an atomic nucleus changes.
- **Examples:** Nuclear power plants, nuclear fusion (in the sun), and radioactive decay.

15.3 Thermal Energy

- **Definition:** Energy associated with the microscopic particles of a system (includes both their kinetic and potential energies).
- **Transformation Example:** Rubbing your hands together.

Kinetic Energy → Thermal Energy

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15.4 Electrical Energy

- **Definition:** Energy associated with charged particles. It can be transmitted through wires and transformed into almost any other form.
- **Examples:**
  - ✓ **Electric fan:** Electrical → Kinetic
  - ✓ **Light bulb:** Electrical → Radiant + Thermal

15.5 Radiant Energy

- **Definition:** Energy transferred by electromagnetic waves.
- **Examples:** Visible light, solar radiation, X-rays, and microwaves.

16. Connecting All Forms of Energy

The Central Idea:

Energy is never lost; it can only be **transferred** (moved from one object to another) and **transformed** (changed from one form to another).

Here is how we trace the "Energy Chain" in real-life examples:

Example 1: Throwing a Ball

1. **Chemical Energy** (from the player's muscles)
2. → **Kinetic Energy** (as the ball is launched)
3. → **Gravitational Potential Energy (GPE)** (as it moves upward)
4. → **Kinetic Energy** (as it falls back downward)

Example 2: Bow and Arrow

Chemical Energy (Archer's muscles) → Elastic PE (Bent bow) → Kinetic Energy (Flying arrow)

Example 3: Electric Fan

Electrical Energy → Rotational Kinetic Energy

Example 4: Electric Light Bulb

Electrical Energy → Radiant Energy (Light) + Thermal Energy (Heat)

The Fireworks Example:

When you experience a fireworks display, you are actually witnessing a massive and rapid **energy transformation**:

1. **The Source:** Energy is initially stored as **Chemical Energy** in the reactive materials inside the fireworks.
2. **The Release:** During the explosion, chemical reactions release this energy instantly.
3. **The Result:** You *see* moving, colorful lights (Kinetic + Radiant), you *hear* loud pops (Sound), and you may even *feel* the warmth given off (Thermal) if you are close enough.

The Energy Chain for Fireworks:

Chemical Energy → Kinetic + Radiant + Sound + Thermal

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Formula Sheet

Concept	Equation
Work–Energy Theorem	$W = \Delta E$
Mechanical Work–Energy	$W = \Delta\text{KE} = \text{KE}_f - \text{KE}_i$
Translational Kinetic Energy	$\text{KE}_{\text{trans}} = \frac{1}{2}mv^2$
Rotational Kinetic Energy	$\text{KE}_{\text{rot}} = \frac{1}{2}I\omega^2$
Total Rolling Kinetic Energy	$\text{KE}_{\text{total}} = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2$
Rolling without slipping	$v = \omega r \Leftrightarrow \omega = \frac{v}{r}$
Gravitational Potential Energy	$\text{GPE} = mgh$
Work Done by Gravity	$W_g = mg(h_i - h_f)$
Work–GPE Relationship	$W_g = -\Delta\text{GPE}$
Rest Energy	$E_0 = mc^2$

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