Name: ____ Block: ________

PHYSICS: UNIT 5
WORK & ENERGY

Work (mechanical or linear) using pushes and pull forces	$W = F \cdot d$	W = work (J) F = magnitude of force (N) d = magnitude of displacement (m)
Work against gravity	$W = m \cdot g \cdot h$	W = work (J) m = mass of object (kg) g = 9.81 h = height (m)
Power	$P = \frac{W}{t}$ or $P = \frac{\Delta E}{t}$	P = power (Watts) W = work (J) ΔE = change in energy (J) t = time (s)
Gravitational potential energy (GPE)	$GPE = m \cdot g \cdot h$	GPE = gravitational potential energy (J) m = mass of object (kg) g = 9.81 h = height (m)
Kinetic energy	$KE = \frac{1}{2} m \cdot v^2$	KE = kinetic energy (J) m = mass (kg) v = velocity (m/s)

PART 1: WORK & POWER

Work is performed when a constant force is exerted on an object parallel to the direction of the object's motion. In other words, work is performed when a force exerted on an object displaces the object (moves the object in a straight line at a given distance). Work is a vector, and may be positive or negative depending on the direction of the applied parallel force moving the object. The premise behind work is that matter has to be physically moved or deformed in some capacity. If the object does not move, then no work has been performed despite the force applied to the object. The units for work are ***Joules***. The work for energy is also Joules because energy is required to perform work.

1 Joule = 1 N·m.   The components of joules are the Newton-meter. 1 Newton-meter is equal to 1 joule of work. (force times displacement).

A. Types of work

There are four types of work that can be performed on matter: (1) work (mechanical), (2) work against resistance, (3) work against shape, and (4) work against gravity. All forms of work are interrelated and each can be classified by the other. They all have motion and forces in common.

- ***Work (mechanical or linear)***: Work in which a push or pull force physically moves an object over a given displacement (straight-line distance). Mechanical or linear work is performed when an object is moved by a force from one location to another.

- ***Work against resistance***: Work in which an object is moved, stretched, or pushed by a force against an opposing force. When the force creating the work against resistance ends, the opposing force tries to restore the position of the moved object. Examples of work against resistance include stretching or compressing a spring, stretching rubber, or moving against wind or river current. Work against resistance will always create ***potential energy***. Work against *friction* is a specific case of work against resistance. Friction is a dissipative force that acts in the direction opposite that of any object's motion over a surface. Friction decreases kinetic energy by creating heat.

- ***Work against shape***: If an applied force causes the physical deformation of matter (stretching, bending, twisting, shattering, breaking, cutting, crushing, melting, compressing, expanding), work is being performed on that matter because the matter's shape, size, or consistency has been changed. Chewing bubble gum is an example of work against shape.

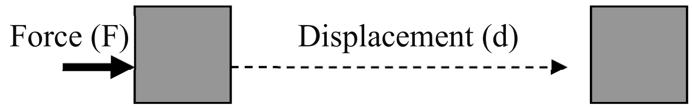
- ***Work against gravity***: Work against gravity is a specific case of work against resistance. Work against gravity is performed when an object is lifted above a permanent surface. Because work is performed in the up direction, up is opposite the downward acceleration due to gravity, work is being performed against gravity.

B. “Mechanical” or “linear” work

Work (mechanical) is calculated as the product of a parallel push or pull force multiplied by the displacement of the object by that force. When a force moves an object, work is performed.

$$W = F \cdot d$$

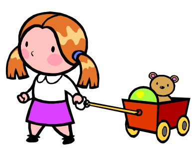
W = work (Joules)
F = magnitude of force (N)
d = magnitude of displacement (m)



Note that work is the product of force and displacement.

- The greater the parallel force, the greater the work performed.
- The greater the displacement of the object, the greater the work performed.
- If the object does not move despite the force being applied, no work will be performed, W = 0.

Illustrative Examples



Little Jane pulls her wagon with a parallel force of 10 N. The wagon moves 10 meters. Calculate the work Jane performs to move the wagon.

$$W = F \cdot d = 10N \cdot 10m = 100\,J$$

Dimitri shopped for groceries at his local market. Dimitri pushes the shopping cart with a parallel force of 15 N to his car. He performs 560 J of total work. How far is his car parked from the door of the market?

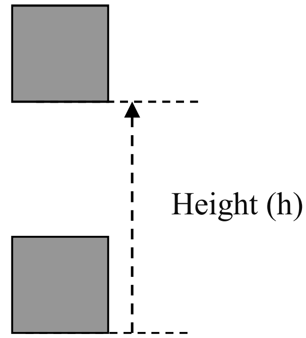
$$d = \frac{W}{F} = \frac{560J}{15N} = 37.3m$$

C. Work against gravity

Work against gravity is the work performed when an object is lifted above a permanent surface to which it may fall. Gravity on Earth accelerates objects in the down direction. When objects are lifted, work is performed in the direction opposite (up) of the direction of gravity (down). Work against gravity is equal to the mass of the object multiplied by acceleration in Earth’s gravity field (g) by height (h) above the permanent surface. Work against gravity will create an equal amount of **gravitational potential energy (GPE).**

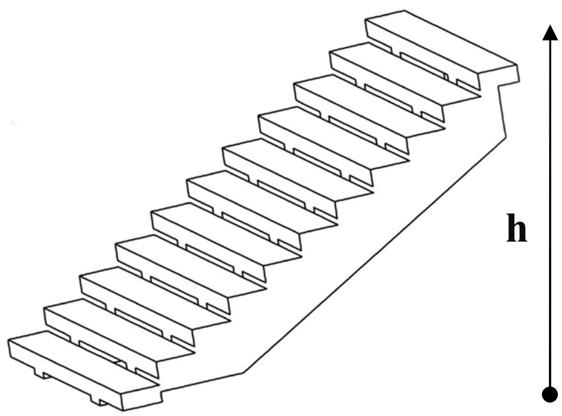
$$W = m \cdot g \cdot h = w \cdot h$$

W = work (joules)
m = mass of object (kg)
g = 9.81
h = height above the surface (m)
w = weight (N)



The object's weight (w) is equal to the product of mass multiplied by the acceleration due to gravity. $w = m \cdot g$. Work performed against gravity is accomplished, the weight of the object is lifted a given height above the permanent surface.

- The product of $m \cdot g$ = weight, which is the force needed to lift the object.
- The greater the mass of the object being lifted, the more work will be performed.
- The greater the *absolute height* above the permanent surface to which the object is lifted, the more work will be performed.



When considering work against gravity, the variable h (height) in the equation of WAG is the absolute height above the permanent surface. People move up and down a staircase by the sloping steps, however, the work they perform by moving themselves up and down the stairs is only dependent on the height difference between where they started moving and where they stopped moving. In the case of the stairs, h would be the height difference between the lower floor and the higher floor, not the actual length of the staircase.

D. Power

Power is the rate at which work is performed. ***Power*** is also the rate at which energy is consumed or produce by matter. Power is calculated as work (or energy) divided by time. The units for power are Watts. 1 Watt = 1 J/s. Watts is in units of joules per second.

- The faster work is performed, the greater the exerted power.
- The slower work is performed, the lesser the exerted power.
- The faster energy is consumed or released by matter, the greater the power.
- The slower energy is consumed or released by matter, the lesser the power.

Power has no effect on work performed. Work can be performed at any rate, slow or fast. For example, if a man pushes a shopping cart with a force of 25 N over a displacement of 30 meters, he accomplishes the same amount of work (750 Joules) regardless if it takes him 10 seconds or 30 seconds to do it. His power, however, will be different. He will exert more power to do the work in 10 seconds and lesser power to do it in 30 seconds because he is performing the work in a shorter amount of time.

Light bulbs are reported in units of Watts and describe the rate at which electricity is consumed by the light bulb as it produces light. A 100 Watt light bulb consumes 100 J of electrical energy per second, whereas a 40 Watt light bulb consumes 40 J of electrical energy per second.

$$P = \frac{W}{t} \quad \text{or} \quad P = \frac{\Delta E}{t}$$

P = power (Watts)
W = work (Joules)
ΔE = change in energy (Joules)
t = time (s)

Illustrative Example

Martin pushed a shopping cart with a force of 20 N for 12 seconds. The cart moved in a 20 m.

- Calculate the work performed on the cart.
- Calculate the power exerted to push the cart.

$$W = F \cdot d$$

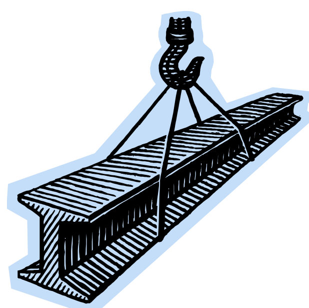
$$W = 20\,N \cdot 20\,m = 400\,J$$

$$P = \frac{W}{t} = \frac{400J}{12s} = 33.3\,Watts$$

Illustrative Example

A crane lifted a 500 kg steel beam from the ground to the top of a tower in 80 seconds. The tower's height was 60 meters.

- Calculate the work performed on the beam.
- Calculate the power exerted by the crane to lift the beam.



$$W = m \cdot g \cdot h$$

$$W = 500kg \cdot 9.83\frac{m}{s^2} \cdot 60m = 294.900J$$

$$P = \frac{W}{t} = \frac{294{,}900J}{80s} = 3686\,Watts$$

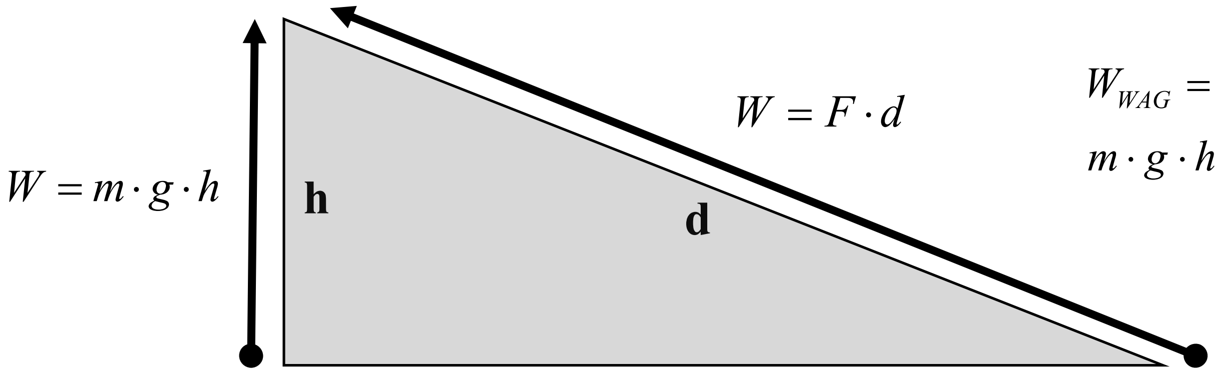
F. Work on an inclined plane

Inclined planes are sloping ramps that connect a lower surface to a higher surface such that loads are moved upward from the lower surface to the higher surface. The inclined plane is one example of a ***simple machine***. Work on an inclined plane is accomplished by pushing an object up the inclined plane's surface rather than by lifting the object straight up to its higher position. Just like all simple machines, inclined planes will perform ***equal amounts of work while using lesser effort force to move an object over a***

greater distance. Less force is required to push an object up the longer sloping surface of the inclined plane rather than lifting the object straight up.

Consider the diagram of the inclined plane. The same object can be moved to the higher position (1) by lifting the object straight up from the permanent surface to the top of the incline (work against gravity), or (2) by pushing the object up the incline's sloping surface ("mechanical" work). In either case, the amount of work performed is the equal despite the two different pathways. (Assume no friction).

Work lifting against gravity = Work pushing up the incline

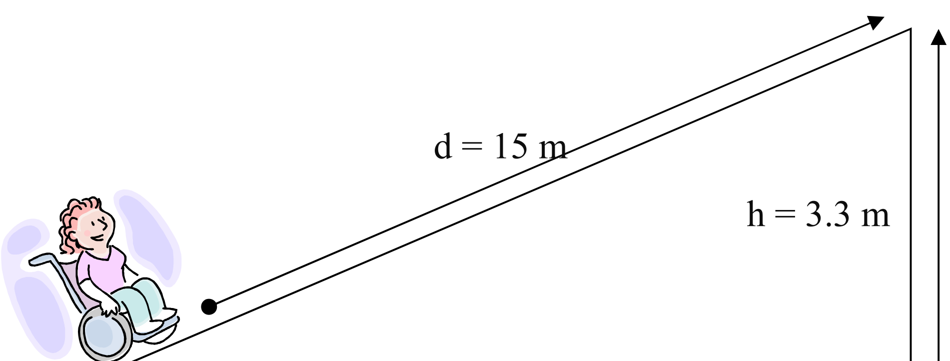


$$W_{WAG} = W_M$$
$$m \cdot g \cdot h = F \cdot d$$

REGARDLESS OF HOW THE OBJECT GETS TO THE TOP OF THE INCLINE, THE WORK PERFORMED IS THE SAME BECAUSE THE OBJECT'S FINAL POSITION AND VERTICAL DISPLACEMENT ARE THE SAME. The overall effect is that the parallel force F exerted by pushing the object up the inclined plane's sloping surface is lesser than lifting the weight of the object (m·g). The compromise is that the distance up the incline plane's sloping surface is greater than the height up the edge of the ramp.

Illustrative Example

Thelma has to wheel herself up the ramp to the school's front door. The height of the ramp is 3.3 meters. The length of the ramp's sloping surface is 15 meters. The combined mass of Thelma and her wheelchair is 70 kg. Calculate the parallel force that Thelma needs to use to push herself and chair up the ramp.



$$Work = WAG$$
$$F \cdot d = m \cdot g \cdot h$$
$$F \cdot 15m = 70kg \cdot 9.83\frac{m}{s^2} \cdot 3.3m$$
$$F = \frac{2271J}{15m} = 151N$$

Thelma must exert a force of 151 N to pull herself up the sloping surface of the incline.

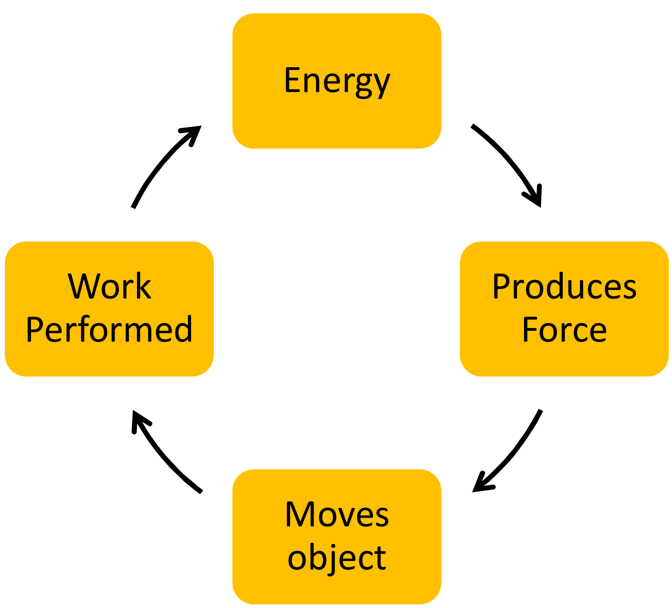
PART 2: ENERGY

Energy is defined at the capacity to perform work. Energy is needed to move objects from one place to another. Energy is needed to change the size or shapes of objects. Energy is needed to convert matter from one form to another. Energy can be transformed, for example, from motion energy into heat energy, or from electricity into light energy.

On Earth, ***> 99.9% of the total sources of energy is directly or indirectly derived from incoming sunlight*** (solar radiation). Solar energy causes many beneficial actions and reactions on Earth that sustains our planet and life. Sunlight is responsible for causing atmospheric motion (winds and weather), ocean circulation (waves and currents), ***photosynthesis***, the production of fossil fuels (coal, petroleum, natural gas), and direct heating of the Earth's surface. The other < 0.1% of the total energy is derived from Earth's internal heat (volcanism and geothermal heat), the moon's gravity (tidal forces), and the Earth's rotation.

A. Work-energy theorem

Energy is the capacity to perform work; energy causes work to be performed. Energy creates a force. That force in turn will move or transform an object, thus producing work. Likewise, when work is performed, work upon matter will create energy. Both work and energy are reported in units of ***Joules***—the same unit because work and energy can produce or be produced from each other. As a result, energy and work have the ability to produce each other. The ability of work to create energy, and for energy to cause work to be performed is known as the ***Work-Energy Theorem***. The ***work energy theorem states*** that *the work performed on an object or on a system is equal to the change in the system's kinetic energy.* In other words, as work is being performed, the kinetic energy in the system will decrease, however, the work will produce a new and different form of energy.



You can think of the Work-Energy Theorem as a cyclical process.

1. Energy creates a force.
2. That force moves an object.
3. The movement of the object by the force is work.
4. As work occurs, kinetic energy of the object or system decreases, but the work creates a new form of energy.
5. Cycle repeats.

One limitation to the Work-Energy Theorem is that ***energy cannot be recycled, only transformed.*** As forms of energy perform work and new forms of energy are created, the work or transformations cannot readily be reversed to extract the exact amount of original energy and the type of original energy that started the process. Consider the process of photosynthesis. **Photosynthesis** occurs in plants and algae where chlorophyll in the chloroplasts organelles in plant cells combines carbon dioxide and water by a photochemical reaction to form sugars and release oxygen.

Sunlight (UV & visible) + **CO_2 & H_2O** → **Plant material (chemical energy)** + **O_2**

When plant material is combusted (set on fire), the burning of the wood and leaves release the stored energy in the forms of heat, some visible light, and some infrared radiation as well as CO_2 and H_2O, and solid residuals like ash and minerals. The **combustion** reaction does not release sunlight, the original form of energy that helped create the plant material. Likewise, you cannot recombine the released heat, visible light, and infrared radiation with the CO_2, H_2O, and ash to get back the stored chemical energy before the combustion or the sunlight that started the photosynthesis.

Plant material (chemical energy) + **O_2** → **Heat** + **Light (Visible and IR)** + **CO_2 & H_2O**

B. Types of energy

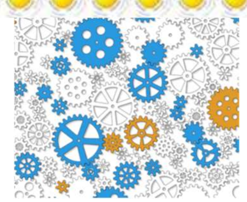
Kinetic Energy: energy attributed to matter in motion; energy in moving objects. All objects in motion, whether at the macroscopic (whole object) or microscopic level (atoms and molecules) have at least one form of kinetic energy.

Translational KE — KE of an object physically moving from one location to another location.

Rotational KE — KE of an object that moves in a circular motion or by rotation.

Vibrational KE — KE of an object or molecules vibrating or moving back-and-forth around a fixed position.

Mechanical KE — KE of machines where a series of interlocking parts (gears, belts, wheels, pistons, cogs, and levers) are all moving at the same time to make the machine function.



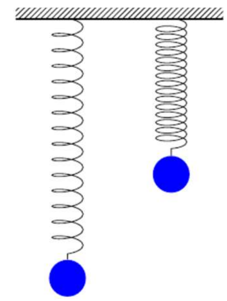
Potential Energy: energy stored in matter to be released; energy created by work against resistance or against force. All forms of potential energy have the potential to be transformed into other forms of energy in the future. ***Work against resistance will produce at least one form of potential energy.***

Gravitational PE

Energy of an object that has been lifted or suspended above a permanent surface. GPE is gained as an object is displaced upward against gravity. GPE is released as an object is displaced downward (falls due to gravity).

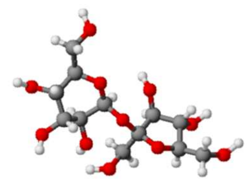
Elastic PE

Energy of an object that has been stretched or compressed against a restoring force. The restoring force wants to restore the object back to its original shape. When the external force causing the stretching or compressing ends, the object will rebound.



Chemical PE

Energy that is stored in chemical bonds in molecules. Chemical energy is released during chemical reactions. Forms of matter with high quantities of chemical PE include fuels, food, and plants (photosynthesis).



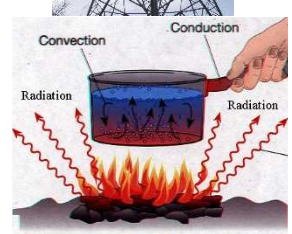
Other forms of Energy

Electricity

Electrical energy occurs when electrons flow through a conductive material under the influence of an electric field.

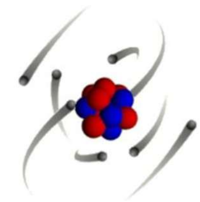
Thermal Energy

Heat. Heat is the measureable transfer of internal energy (energy of molecules) between molecules or through matter.



Radiant Energy

Light. Photons carry energy through space by electromagnetic waves. Radiant energy can be released from matter by chemical reactions, the reduction in heat or internal energy, or by nuclear fission/fusion.

Nuclear Energy	Energy released during nuclear reactions when nuclei of atoms fuse (fusion) or disintegrate (fission). Nuclear energy is derived from the energy holding neutrons and protons together in the nuclei.	

C. Gravitational potential energy (GPE)

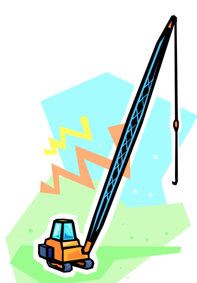
All work performed against gravity will produce an equal amount of ***gravitational potential energy (GPE)***. GPE is the **"stored energy"** in an object that has been lifted or suspended above a permanent surface to which it may fall. Like all forms of ***potential energy***, GPE is "stored" energy. The object has stored energy that has the potential to be released if the object was allowed to fall (or slide, walk, or roll if on an incline plane) downward toward the permanent surface.

It is not a coincidence that **GPE** and **work against gravity** have the same mathematical equation. Both are dependent on the absolute vertical distance that an object is raised above the permanent surface (work), the greater the stored energy in the object that may be released if it were allow to fall down to the permanent surface (GPE).

$$GPE = m \cdot g \cdot h$$

GPE = gravitational potential energy (joules)
m = mass of lifted or suspended object (kg)
g = 9.81
h = height above the surface (m)

Illustrative Examples



A crane lifts a steel beam from the ground to the top of a building that is under construction. The beam has a mass of 300 kg. The crane lifts the beam 22 meters above the ground. Calculate the work performed to lift the beam and the gravitational potential energy attributed to the beam.

$$W = m \cdot g \cdot h = 300kg \cdot 9.83\frac{m}{s^2} \cdot 22m = 64{,}880\ \ J$$

$$GPE = m \cdot g \cdot h = 300kg \cdot 9.83\frac{m}{s^2} \cdot 22m = 64{,}880\ \ J$$

Harmon walks up three flights of stairs to get to his office. The third floor is 12 meters above the ground floor. Harmon's mass is 80 kg. Calculate the work Harmon performs to go up the stairs.

$$W = m \cdot g \cdot h = 80kg \cdot 9.83\frac{m}{s^2} \cdot 12m = 9440\ J$$

$$GPE = m \cdot g \cdot h = 80kg \cdot 9.83\frac{m}{s^2} \cdot 12m = 9440J$$

B. Translational kinetic energy

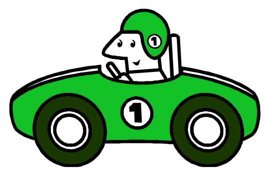
Translational kinetic energy (KE) is the energy attributed to an object in motion moving from one location to another. KE is calculated as ½ multiplied by the mass of the object (kg) multiplied by the velocity squared. KE is a scalar parameter and describes the moving energy of an object. Kinetic energy, like all forms of energy, is reported in units of Joules (J).

$$KE = \frac{1}{2} m \cdot v^2$$

KE = translational kinetic energy (joules)
m = mass of object moving (kg)
v = velocity of object in motion (m/s)

Illustrative Example

The racecar moves with a velocity of 42 m/s. The mass of the racecar is 700 kg. Calculate the translational KE of the racecar.



$$KE = \frac{1}{2} \cdot m \cdot v^2$$

$$KE = \frac{1}{2} \cdot 700kg \cdot \left(42\frac{m}{s}\right)^2$$

$$KE = 617{,}400\ J$$

Note that the velocity (v) in the kinetic energy equation is squared—as velocity increases, the quantity of KE exponentially increases. For example, if the speed of an object doubles, the KE attributed to that object quadruples. If the speed of an object triples, the KE attributed to that object increases nine-fold. A small increase in velocity will yield a very large increase in translational KE.

Illustrative example

Calculate and compare the skater's kinetic energies as his velocity increases.

Timmy has a mass of 40 kg. He rides his skateboard with a *velocity of 2.0 m/s*.

$$KE = \frac{1}{2} \cdot m \cdot v^2 = \frac{1}{2} \cdot 40kg \cdot \left(2.0 \, {}^{m}\!/_{s}\right)^2$$

$$KE = 80J$$

Timmy skates faster down a hill with a *velocity of 4.0 m/s*.

$$KE = \frac{1}{2} \cdot m \cdot v^2 = \frac{1}{2} \cdot 40kg \cdot \left(4.0 \, {}^{m}\!/_{s}\right)^2$$

$$KE = 320J$$

Timmy skates very fast down a very steep hill with a *velocity of 8.0 m/s*.

$$KE = \frac{1}{2} \cdot m \cdot v^2 = \frac{1}{2} \cdot 40kg \cdot \left(8.0 \, {}^{m}\!/_{s}\right)^2$$

$$KE = 1280J$$

The skater's original kinetic energy was 80 J when he moved at 2.0 m/s. When his velocity was doubled to 4.0 m/s, his kinetic energy quadrupled (increased 4-times) to 320 J. When his velocity was doubled again to 8.0 m/s, his kinetic energy was 4-times greater than his kinetic energy at 4.0 m/s and 16-times greater than his kinetic energy at 2.0 m/s.

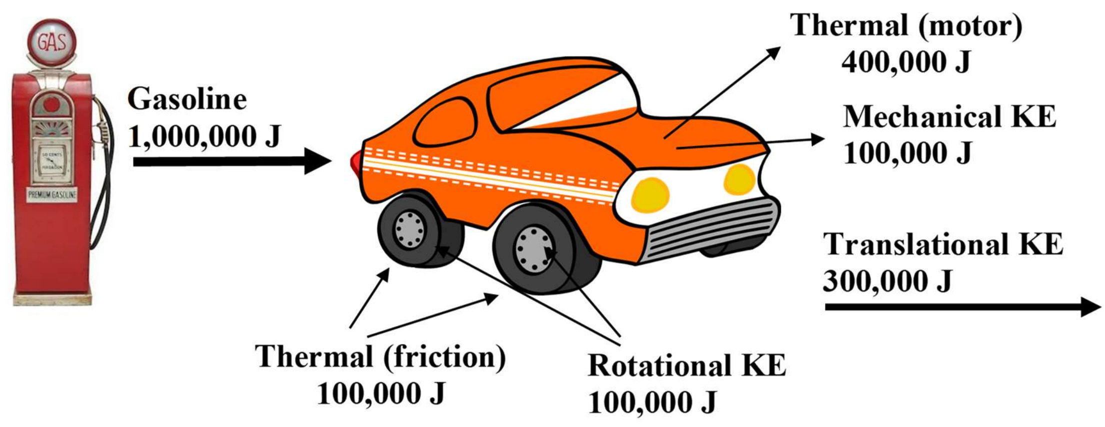
D. Law of conservation of energy

Law of Conservation of Energy: *The total energy in a closed system remains constant. Energy is neither created nor destroyed, but is transformed from one form of energy to other forms of energy*.

In other words, as energy is used to produce work, energy can change forms, however, no energy is lost nor gained during this process. The total energy of the system remains the same. Some forms of energy may be greater than others. Over time, the individual forms of energy may change proportion or quantity, however, the total energy remains constant—all forms of energy in that object must always add up to the total energy.

Illustrative example

Gasoline (chemical potential energy) is the energy used by the automobile's motor to make the automobile move (physical work). In the process of making the car go, the gasoline is converted into many different forms of energy. Some of the gasoline's energy is converted to non-practical heat (thermal) in the engine. Some makes the motor function (mechanical KE) which powers the wheels (rotational KE) and makes the car physically move (translational KE). Additionally, some of the wheels' kinetic energy is transformed to friction (thermal) as they roll over the road's surface.



Regardless of how many new forms of energy were created by the car, energy cannot be created nor destroyed, only transformed as the work is performed. If all of the forms of energy were added together, that sum must equal the original 1,000,000 Joules of energy in the gasoline.

PART 3: LAW OF CONSERVATION OF ENERGY

Law of Conservation of Energy: *The total energy in a closed system remains constant. Energy is neither created nor destroyed, but is transformed from one form of energy to other forms of energy*.

If an object moves in Earth's gravity field, the proportions of GPE and KE will change accordingly if the object is moving up (against gravity) or moving down (in favor of gravity). At any given position in the object's motion, the total energy attributed to the object (TOT E) will be the sum of the object's gravitational potential energy and kinetic energy.

$$TOT\ E = GPE + KE$$

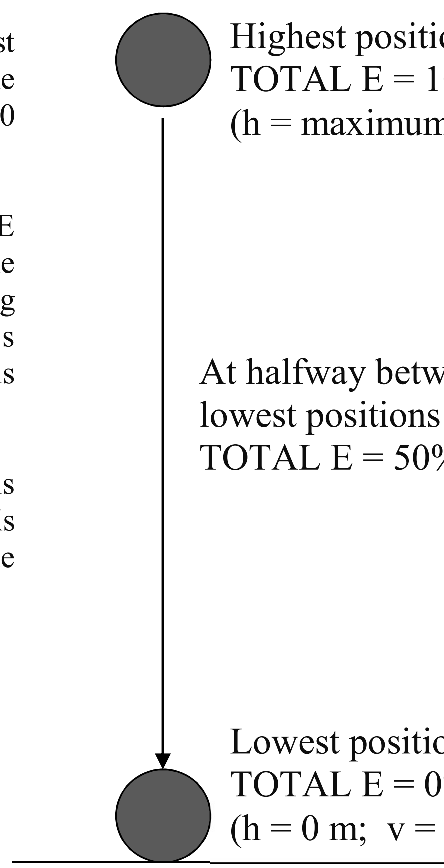
Because the law of conservation of energy applies, TOT E must remain constant, however, the proportions and quantities of GPE and KE can change depending on the height above the ground and direction of motion. Assume that no friction or air resistance are negligible.

Illustrative example: Freefall

The object is released from the highest position above the ground from rest. At the highest position, GPE is 100%. KE is 0 because the object is initially motionless.

As the object moves downward, GPE decreases because object's height above the permanent surface is decreasing (h is getting smaller). KE increases because the object's velocity is getting faster the farther it falls downward.

At impact, the object has 0 GPE because it is at the lowermost surface, h = 0. The KE is 100% because the object's velocity is the fastest at impact.

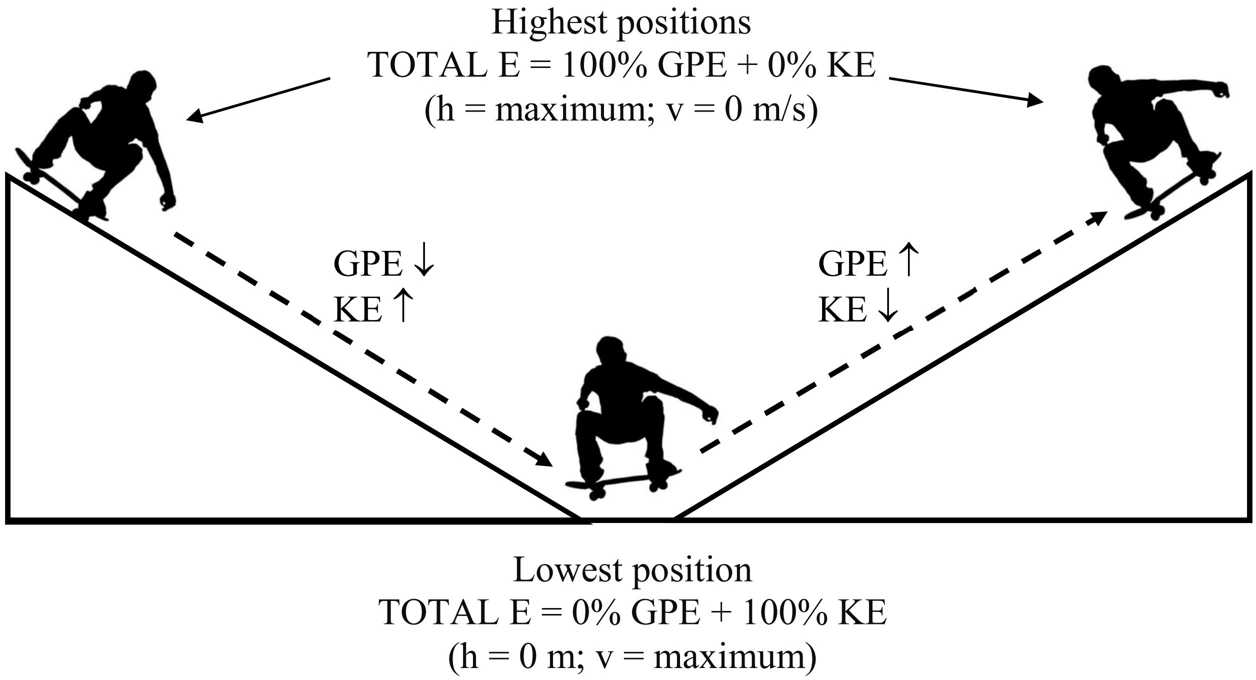


Highest position (release)
TOTAL E = 100% GPE + 0% KE
(h = maximum; v = 0 m/s)

At halfway between highest and lowest positions
TOTAL E = 50% GPE + 50% KE

Lowest position (impact)
TOTAL E = 0% GPE + 100% KE
(h = 0 m; v = maximum)

Illustrative example: Skate park



The skateboarder begins at the top of the U on the left side. His total energy at the top of the ramp is: TOT E = 100% GPE + 0% KE. GPE is 100% because he is at the highest position (h = maximum). KE is 0% because the skateboarder is motionless (v = 0 m/s).

He skates down the left ramp. His GPE decreases because he is getting physically lower to the ground (h decreasing). His KE increases because his velocity is increasing (v increasing).

At the bottom of the ramp, the skateboarder is at the permanent surface. GPE is 0% because the boy is at the lowermost surface (h = 0). His KE is 100% because he is moving the fastest (v = maximum).

He skates up the right ramp. His GPE increases because he is getting physically higher above the ground (h increasing). His KE decreases because his velocity is slowing (v decreasing).

The skateboarder reaches the top of the opposing ramp. His total energy at the top of the ramp is: TOT E = 100% GPE + 0% KE. GPE is 100% because he is at the highest position (h = maximum). KE is 0% because the skateboarder is motionless (v = 0 m/s).

Illustrative example: Vertical projectile

At launch, the projectile is moving with the fastest upward direction. Because it is at ground level, h = 0 m and GPE = 0, thus it has 100% KE. As the projectile moves upward, its velocity decreases as the height increases: KE decreases and GPE increases. At the highest position above the ground, the projectile stops for an instant as it changes direction. Because it is motionless, v = 0 m/s and KE = 0%, and because it is at the highest position above the ground, h = maximum and GPE = 100%. As the projectile freefalls to the ground, its velocity increases while its height decreases: KE increases and GPE decreases. At impact with the ground (position E), the projectile moves with the fastest downward velocity, v = maximum, KE = 100%. Because it impacts the ground, h = 0 m, therefore GPE = 0%.