Chapter 5. ENERGY

1) Work and power of a force
2) Energy and Mechanical Energy
3) Kinetic Energy
4) Work and Kinetic Energy theorem
5) Gravitational Potential Energy
6) Elastic Potential Energy
7) Conservative and Non-conservative Forces
8) Conservation of Energy

Physics (Phys225) at HUST

5.1. Work W and power P (of a force)

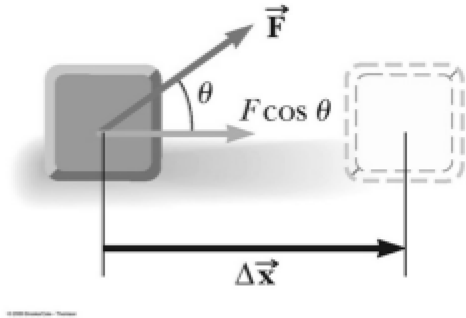
- Start with: $v^2 - {v_0}^2 = 2a_x\Delta x$ =>

$$\frac{1}{2}mv^2 - \frac{1}{2}m{v_0}^2 = ma_x\Delta x = F_x\Delta x \longrightarrow \text{Work “W”}$$

- Work provides a link between force and energy
- Work done on an object is transferred to/from it
- If W > 0, energy added: “transferred to the object”
- If W < 0, energy taken away: “transferred from the object”

5.1.1. Definition of Work W

- The work, W, done by **a constant force** on an object is defined as the product of the component of the force along the direction of displacement and the magnitude of the displacement



$$\boxed{W \equiv (F\cos\theta)\Delta x = \vec{F}.\Delta\vec{x}}$$

where:

F is the magnitude of the force

Δx is the magnitude of the object's displacement

θ is the angle between $\vec{F}$ and $\Delta\vec{x}$

- In the case of a **differential displacement** $d\vec{x}$

  the work done by the force is

$$dW \equiv (F\cos\theta)dx = \vec{F}.d\vec{x}$$

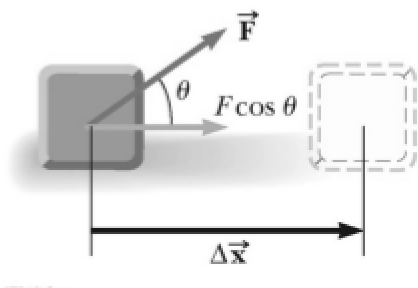
- Work is a scalar quantity, SI Unit **J = kg.m²/s²**

5.1.2. Work: + or –?

- Work can be positive, negative, or zero. The sign of the work depends on the direction of the force relative to the displacement

$$W \equiv (F\cos\theta)\Delta x$$

- ♣ Work positive: $W > 0$ if $90^\circ > \theta > 0^\circ$
- ♣ Work negative: $W < 0$ if $180^\circ > \theta > 90^\circ$
- ♣ Work zero: $W = 0$ if $\theta = 90^\circ$
- ♣ Work maximum if $\theta = 0^\circ$
- ♣ Work minimum if $\theta = 180^\circ$



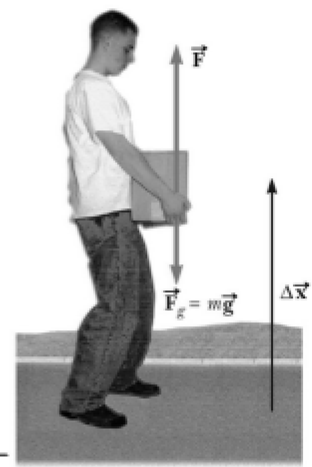
Example 1: When Work is Zero

- A man carries a bucket of water horizontally at constant velocity.
- The force does no work on the bucket
- Displacement is horizontal
- Force is vertical
- $\cos 90° = 0$

$$\boxed{W = (F\cos\theta)\Delta x = 0}$$

Example 2: Work Can Be Positive or Negative

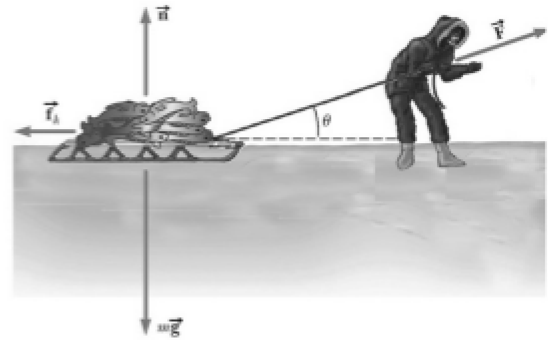
- Work (of force F) is positive when lifting the box
- Work would be negative if lowering the box
  - The force would still be upward, but the displacement would be downward



Example 3: Work and Force

- An Eskimo pulls a sled as shown. The total mass of the sled is 50.0 kg, and he exerts a force of 1.20×10^2 N on the sled by pulling on the rope. How much work does he do on the sled if $\theta = 30^\circ$ and he pulls the sled 5.0 m ?

$$\begin{aligned} \boldsymbol{W} &= (\boldsymbol{F}\cos\boldsymbol{\theta})\boldsymbol{\Delta x} \\ &= (\mathbf{1.20} \times \mathbf{10^2}\boldsymbol{N})(\mathbf{cos\,30^\circ})(\mathbf{5.0}\boldsymbol{m}) \\ &= \mathbf{5.2} \times \mathbf{10^2}\boldsymbol{J} \end{aligned}$$

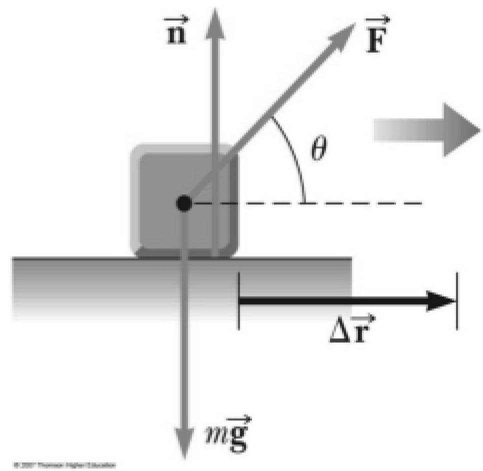


Work Done by Multiple Forces

- If more than one force acts on an object, then the total work is equal to the algebraic sum of the work done by the individual forces

$$W_{\text{net}} = \sum W_{\text{by individual forces}}$$

- Remember work is a scalar, so this is the algebraic sum



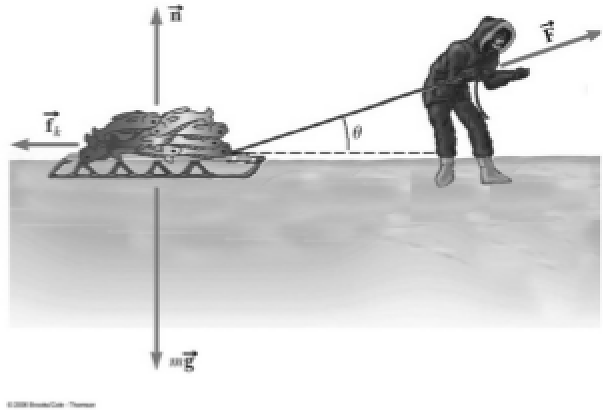
An example:

$$W_{net} = W_g + W_N + W_F = (F\cos\theta)\Delta r$$

Work and Multiple Forces

- Suppose $\mu_k = 0.200$, How much work done on the sled by friction, and the net work if $\theta = 30^\circ$ and he pulls the sled 5.0 m ?

$$\boxed{\begin{aligned} F_{net,y} &= N - mg + F\sin\theta = 0 \\ N &= mg - F\sin\theta \end{aligned}}$$



$$W_{fric} = (f_k \cos 180^\circ)\Delta x = -f_k \Delta x$$
$$= -\mu_k N \Delta x = -\mu_k (mg - F\sin\theta)\Delta x$$
$$= -(0.200)(50.0kg \cdot 9.8m/s^2$$
$$-1.2 \times 10^2 N \sin 30^\circ)(5.0m)$$
$$= -4.3 \times 10^2 J$$

$$W_{net} = W_F + W_{fric} + W_N + W_g$$
$$= 5.2 \times 10^2 J - 4.3 \times 10^2 J + 0 + 0$$
$$= 90.0J$$

5.1.3. Work done by a changing force

- The work, *dW*, **done by a force** in a differential displacement $d\vec{x}$

$$dW \equiv (F\cos\theta)dx = \vec{F}.d\vec{x}$$

- The work, *W*, **done by a force** in a displacement from position (1) to position (2)

$$W = \int_1^2 dW \equiv \int_1^2 (F\cos\theta)dx = \int_1^2 \vec{F}.d\vec{x}$$

And,

$$W = \int_1^2 \vec{F}.d\vec{x} = \int_1^2 m\vec{a}.d\vec{x} = \int_1^2 m\frac{d\vec{v}}{dt}.d\vec{x}$$

$$W = \int_1^2 md\vec{v}\frac{d\vec{x}}{dt} = \int_1^2 m\vec{v}d\vec{v} = \frac{1}{2}mv_2^2 - \frac{1}{2}mv_1{}^2$$

=> Work-Kinetic Energy Theorem

5.1.4. Power of a force

- Power is defined as work done per time unit: $\boxed{\boldsymbol{P = \frac{dW}{dt}}}$

$$dW = \vec{F}.d\vec{r} \;\; \rightarrow \;\; P = \frac{\vec{F}.d\vec{r}}{dt} = \vec{F}.\frac{d\vec{r}}{dt} \;\; \rightarrow \boxed{\boldsymbol{P = \vec{F}.\vec{v}}}$$

Power is equal to the dot product of force and velocity.

- **The average power** is given by

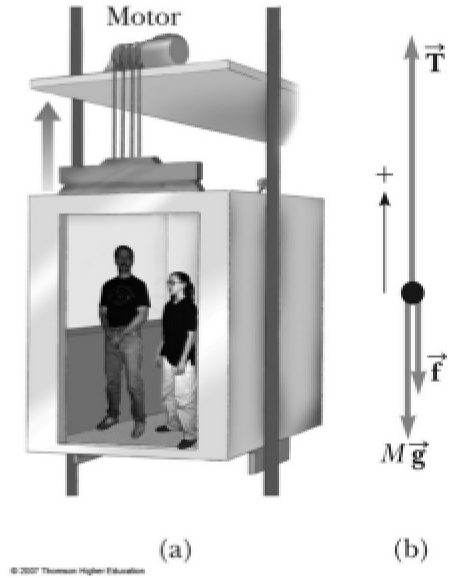
$$\overline{\boldsymbol{P}} = \frac{W}{\Delta t} = \frac{F\Delta x}{\Delta t} = F\bar{v} \qquad \text{(1-D motion, } \bar{v} \text{ average velocity)}$$

Note:

- Work and power are **scalar** quantities.
- Work is measured in joule(s): $J = Nm = kg.m^2.s^{-2}$
- **Power** is measured in **watt**(s): $W = J.s^{-1} = kg.m^2.s^{-3}$
- Kilowatt-hour is the unit of energy: $kWh = 3.6 \times 10^6$ J.

Example 4. Power Delivered by an Elevator Motor

A 1000-kg elevator carries a maximum load of 800 kg. A constant frictional force of 4000 N retards its motion upward. What minimum power must the motor deliver to lift the fully loaded elevator at a constant speed of 3 m/s?



$$F_{net,y} = ma_y$$

$$T - f - Mg = 0$$

$$T = f + Mg = 2.16 \times 10^4 N$$

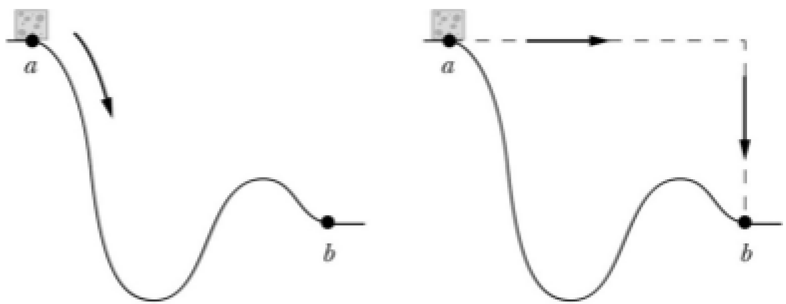
$$P = Tv = (2.16 \times 10^4 N)(3 m/s)$$
$$= 6.48 \times 10^4 W$$

$$P = 64.8\ kW$$

5.2. Energy and Mechanical Energy

Why Energy?

- *Why do we need a concept of energy ?*
- The energy approach to describing motion is particularly useful when Newton's Laws are difficult or impossible to use.
- Energy is a scalar quantity. It does not have a direction associated with it.



5.2. Energy and Mechanical Energy

- **Giancoli,**

  "Energy is one of the most important concepts in science. Yet we cannot give a simple general definition of energy in only a few words. Nonetheless, each specific type of energy can be defined fairly simply."

♣ Traditional definition

Energy is the ability to do work.

Energy of a system depends on the state of the system. Differentiation of energy is a total differentiation

5.2. Energy and Mechanical Energy

- Energy can exist in many different types (forms).

  "The crucial aspect of energy is that the sum of all types, the total energy, is the same after any process as it was before: that is, energy is a conserved quantity." - Giancoli.

- **Law: "**Energy can be transferred or transformed but can never be destroyed or created."
- A perpetual motion machine of the first kind is the machine which produces work without the input of energy.
- Consequence "It is impossible to have perpetual motion machines of the first kind"

5.2. Energy and Mechanical Energy

What is Energy?

- Energy is a property of the state of a system, not a property of individual objects: we have to broaden our view.
- Some forms of energy:
  - **Mechanical:**
    - Kinetic energy (associated with motion, within system)
    - Potential energy (associated with position, within system)
  - **Chemical**
  - **Electromagnetic**
  - **Nuclear**
- Energy is conserved. It can be transferred from one object to another or change in form, but cannot be created or destroyed

5.3. Kinetic Energy, KE

- Kinetic energy is the energy due to motion.
- A particle is accelerated by force $\vec{F} = m\vec{a}$.
- By conservation of energy, work done by $\vec{F}$ is equal to th change in kinetic energy of the particle.

$$dE_k = dW = \vec{F}.d\vec{r} = m\vec{a}.d\vec{r} = m\frac{d\vec{v}}{dt}.d\vec{r} = m.d\vec{v}\frac{d\vec{r}}{dt}$$

$$dKE = m\vec{v}.d\vec{v} = md\left(\frac{\vec{v}^2}{2}\right) = md\left(\frac{v^2}{2}\right)$$

So: $KE = \frac{mv^2}{2} + constant$

- The constant is zero because $E_k = 0$ when $v = 0$

  So, KE of a point mass with velocity v is

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

- SI unit of kinetic energy, [KE] = joule (J)

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

5.4. Work-Kinetic Energy Theorem

- **Work done by a force**

$$W = \int_{12} dW = \int_{12} dKE = \frac{mv_2^2}{2} - \frac{mv_1^2}{2} = KE_2 - KE_1 = \Delta KE$$

Change in kinetic energy is equal to work done by external forces.

- When work is done by a net force on an object and the only change in the object is its speed, the work done is equal to the change in the object's kinetic energy

Speed will increase if work is positive

Speed will decrease if work is negative

$$W_{net} = KE_{final} - KE_{initial} = \Delta KE$$

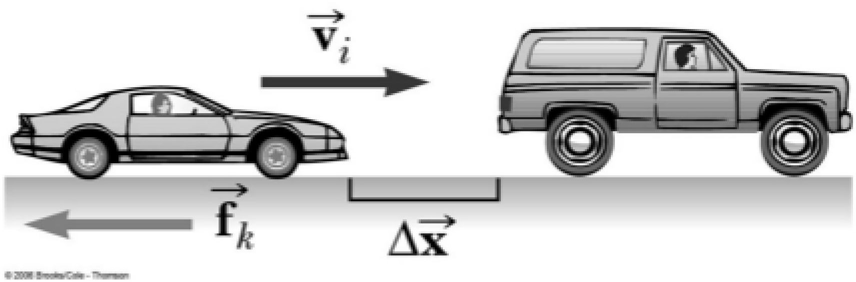
$$W_{net} = \frac{1}{2}mv^2 - \frac{1}{2}mv_0{}^2$$

Example 5: Work and Kinetic Energy

- The driver of a 1.0×10^{3} kg car traveling on the interstate at 35.0 m/s slam on his brakes to avoid hitting a second vehicle in front of him, which had come to rest because of congestion ahead. After the breaks are applied, a constant friction force of 8.0×10^{3} N acts on the car. Ignore air resistance.

(a) At what minimum distance should the brakes be applied to avoid a collision with the other vehicle?

(b) If the distance between the vehicles is initially only 30.0 m, at what speed would the collisions occur?



Example 5: Work and Kinetic Energy

$$v_0 = 35.0m/s, v = 0, m = 1.00 \times 10^3 kg, f_k = 8.00 \times 10^3 N$$

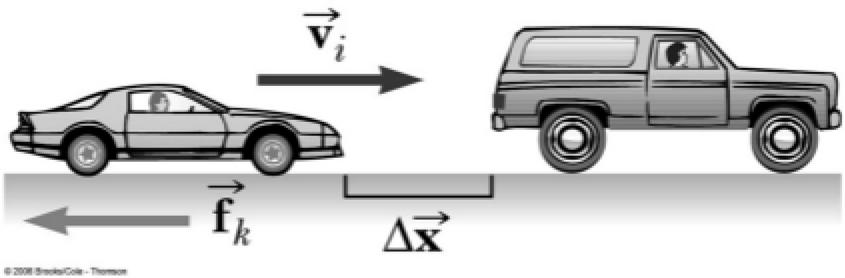
- (a) We know
- Find the minimum necessary stopping distance

$$W_{net} = W_{fric} + W_g + W_N = W_{fric} = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

$$-f_k \Delta x = 0 - \frac{1}{2}mv_0^2$$

$$-(8.00 \times 10^3 N)\Delta x = -\frac{1}{2}(1.00 \times 10^3 kg)(35.0m/s)^2$$

$$\Delta x = 76.6m$$



Example 5: Work and Kinetic Energy

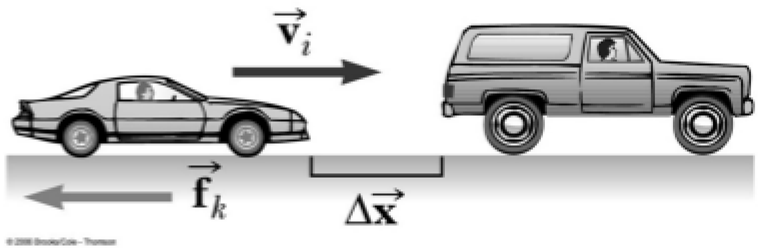
- (b) We know $\Delta x = 30.0m, v_0 = 35.0m/s, m = 1.00 \times 10^3 kg, f_k = 8.00 \times 10^3 N$
- Find the speed at impact.
- Write down the work-energy theorem:

$$W_{net} = W_{fric} = -f_k \Delta x = \frac{1}{2} m v_f^2 - \frac{1}{2} m v_i^2$$

$$v_f^2 = v_0^2 - \frac{2}{m} f_k \Delta x$$

$$v_f^2 = (35m/s)^2 - (\frac{2}{1.00 \times 10^3 kg})(8.00 \times 10^3 N)(30m) = 745 m^2/s^2$$

$$v_f = 27.3m/s$$



$v_0 = 35.0m/s, v = 0, m = 1.00 \times 10^3 kg, f_k = 8.00 \times 10^3 N$

Chapter 5. Energy (cont.)

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5) **Gravitational Potential Energy**
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7) Conservative and Non-conservative For
8) Conservation of Energy

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5.5. Gravitational Potential Energy

5.5.1. Newton's law of Gravitation

Universal gravitation:

- My grandma told me that the Earth was flat, above the sky was the heaven and under the ground was the hell.
  - If the Earth is a sphere, how can people on the other side stay on the ground? Would they fall out of the Earth?
- Physics helps me know that people all around the spherical Earth are attracted by a force of gravity (gravitational force).

We are acted by the gravity because we have a mass.

The Earth gives the force because it has a mass

The origin of gravitational force is the mass.

5.5. Gravitational Potential Energy

5.5.1. Newton’s law of Gravitation

Universal gravitation:

- **Newton** was inspired by the **apple incident**.
  - If gravity acts at the top of a tree then perhaps it acts all the way to the Moon. This produces a force that keeps the Moon in its orbit around the Earth.
  - In the next step, he believed that what keeps the planets in their orbits around the Sun is also the gravitational force.
  - Furthermore, if gravity acts between these objects, why not between all objects on the universe?

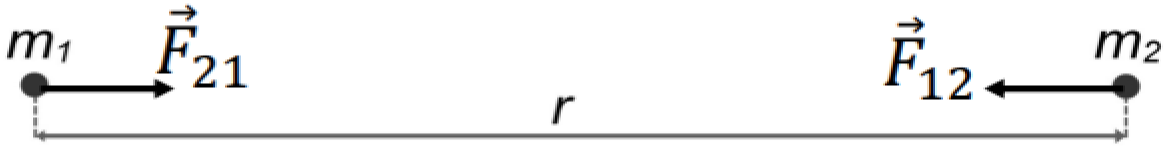
Gravitational force is universal.
(It appears for any objects which have masses.)

5.5. Gravitational Potential Energy

5.5.1. Newton’s law of Gravitation

Statement:

- Two point masses attract each other with a force which is proportional to the product of their masses and inversely proportional to the square of their separation.



$F \propto m_1 m_2$ $\qquad$ $F \propto \frac{1}{r^2}$ $\longrightarrow$ $\boxed{\boldsymbol{F = G\frac{m_1 m_2}{r^2}}}$

- The **coefficient G** is called the **gravitational constant.**

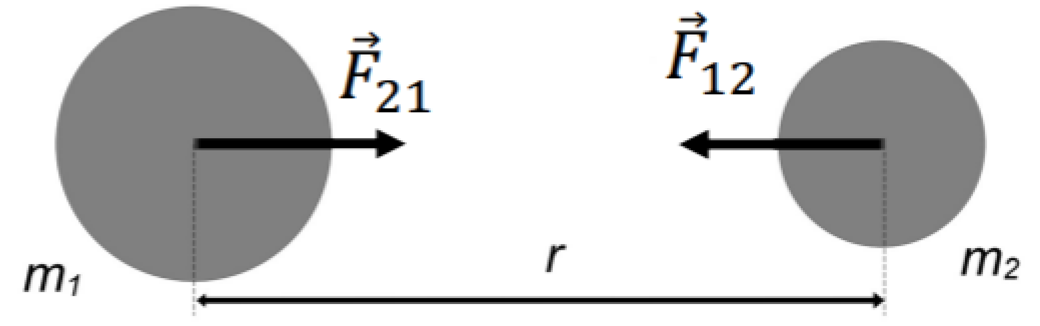
$$\boxed{G = 6.67 \times 10^{-11}\ \mathrm{Nm^2\,kg^{-2}}}$$

5.5. Gravitational Potential Energy

5.5.1. Newton's law of Gravitation

Note that:

- The law is stated for two point masses.
- However, it can be applied for 2 uniform spheres with r is the distance between **their centers**.

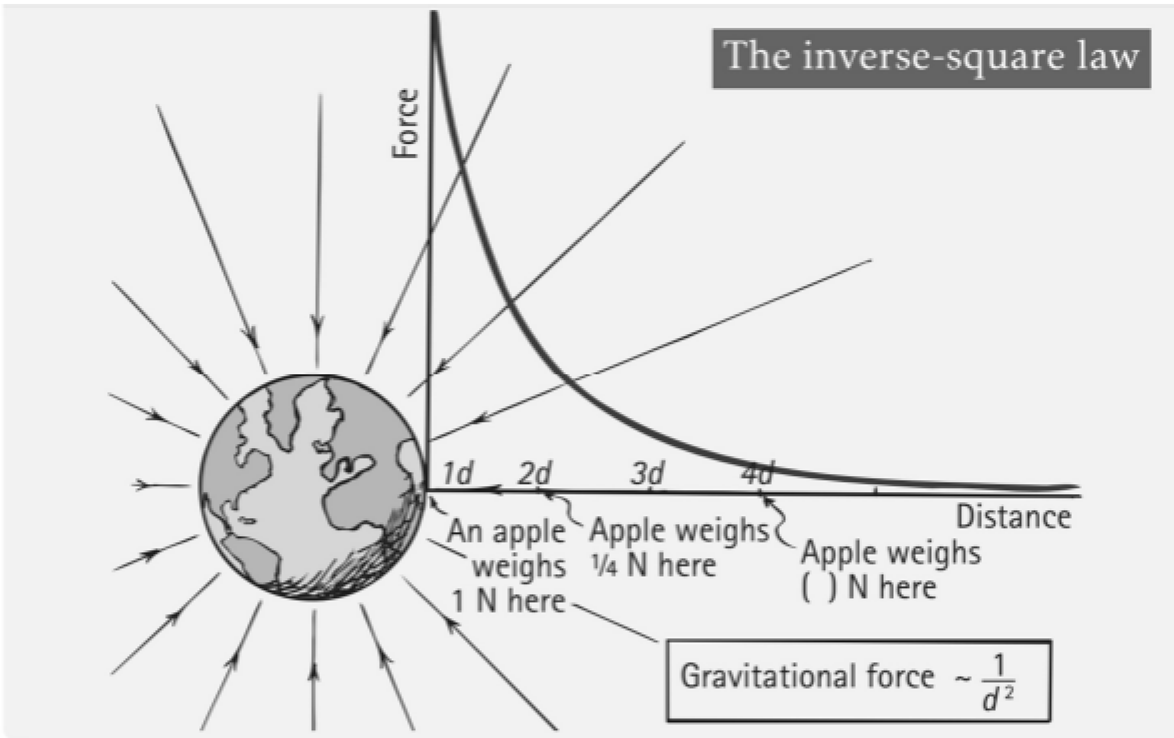


The origin of gravitational force is the mass.

5.5. Gravitational Potential Energy

5.5.1. Newton's law of Gravitation

$$\boxed{F = G\frac{m_1 m_2}{r^2}}$$



5.5. Gravitational Potential Energy

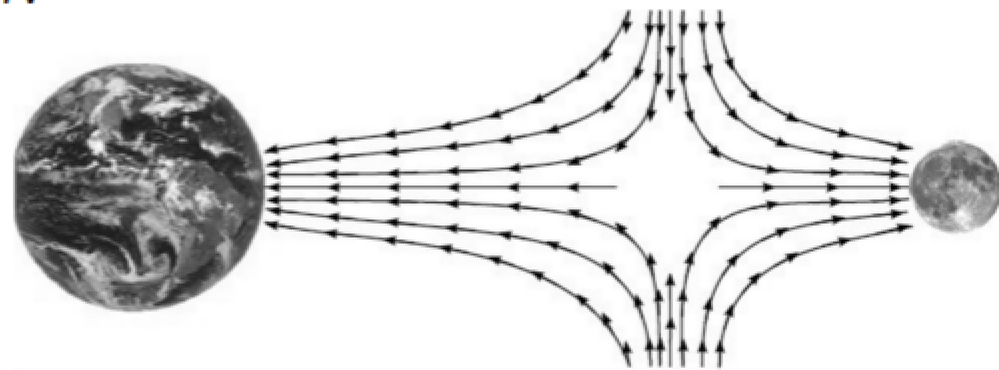
5.5.2. Gravitational field

- When two objects interact each other, what must they do?

  They must be **in contact** or must generate a **field** to transfer the forces.

  - **contact forces**
  - and **field forces**.

- Gravitational force is a field force. When two masses interact, each mass generates a **gravitational field** around it. The field then transmits a force to the other.



5.5. Gravitational Potential Energy

5.5.2. Gravitational field

A gravitational field is a region of space where a mass experiences a force

- To represent for the field, we use **field strength** or **potential**.

The gravitational field strength at a point is the force per unit mass acting on a small test mass placed at the point.

$$\vec{g} = \frac{\vec{F}}{m}$$

The gravitational potential at a point is the work done per unit mass in bringing a small test mass from infinity to the point.

$$\emptyset = \frac{W}{m}$$

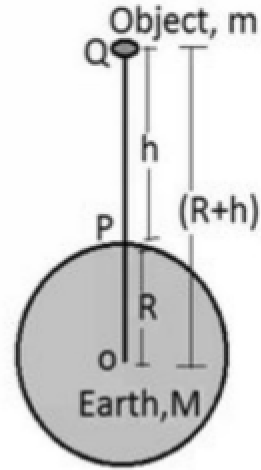
5.5. Gravitational Potential Energy

5.5.2. Gravitational field

♣ Gravitational field of the Earth (mass M; radius R)

• Force acting on a test mass *m* at distance *r* or at height *h*:

$$F = G\frac{Mm}{r^2} = G\frac{Mm}{(R+h)^2}$$



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The gravitational field strength:

$$g = \frac{F}{m} = G\frac{M}{r^2} \quad => \quad g = G\frac{M}{(R+h)^2}$$

• At a higher altitude, the field is weaker. However, since the radius *R* of the Earth is about 6400 km, a change in height of **a few kilometers** causes almost **no change** in the field.

5.5. Gravitational Potential Energy

5.5.3. Work done by Gravitational force and PE

Work done by gravitational force in bringing the mass m from distance r_1 to distance r_2 :

$$W = \int_{r_1}^{r_2} \vec{F} d\vec{r} = \int_{r_1}^{r_2} F.\cos 180^o \, dr = -\int_{r_1}^{r_2} G\frac{Mm}{r^2} dr = G\frac{Mm}{r}\bigg|_{r_1}^{r_2}$$

$$W = -G\frac{Mm}{r_1} - \left(-G\frac{Mm}{r_2}\right)$$ $\notin$ path

Work-energy theorem: Work done = $-\Delta PE = PE_1 - PE_2$

- So, the potential energy at distance r:

$$PE(r) = -G\frac{Mm}{r} + constant$$

- *constant* =? depend on where to chose PE=0.

♣ **If $PE = 0$ at $r = \infty$**, then const. = 0. => $PE(r) = -G\frac{Mm}{r}$

For the gravitational field of the Earth, we often chose $PE = 0$ at r = R (at surface of the Earth). => $PE(h) \equiv mgh$

(cont. next slide)

5.5. Gravitational Potential Energy

5.5.3. Work done by Gravitational force and PE (cont.)

$$\boldsymbol{PE(r) = -G\frac{Mm}{r} + const}$$

For the gravitational field of the Earth, we often chose $PE = 0$ at r = R (at surface of the Earth).

$$\boldsymbol{PE(R) = -G\frac{Mm}{R} + const = 0}$$

In such case: $\boldsymbol{const = G\frac{Mm}{R}}$

For, $r = R{+}h$

=> $PE(h) = PE(r) = -G\frac{Mm}{r} + G\frac{Mm}{R}$

$$PE(h) = -G\frac{Mm}{R+h} + G\frac{Mm}{R} = G\frac{Mmh}{R(R+h)}$$

If h << R, then $G\frac{M}{R(R+h)} \approx g_0$ **gravitational field strength** (also free fall acceleration) at the surface of the Earth.

$\boldsymbol{PE(h) \equiv mgh}$

5.5. Gravitational Potential Energy

5.5.3. … and Potential Energy

$$\boldsymbol{PE(r) = -G\frac{Mm}{r} + const}$$

If $PE = 0$ at $r = \infty$, then const. = 0. => $\boldsymbol{PE(r) = -G\frac{Mm}{r}}$

=> In this case, Work done by gravitational force in bringing the mass m from distance r to infinity ∞ is the gravitational potential energy of the mass:

$$\boldsymbol{W = PE = \int_r^{\infty}\vec{F}d\vec{r} = -\int_r^{\infty}G\frac{Mm}{r^2}dr = G\frac{Mm}{r}\Big|_r^{\infty} = -G\frac{Mm}{r}}$$

- Gravitational potential at distance r: $\emptyset = \frac{PE}{m} = -G\frac{M}{r}$

Reference Levels

- A location where the gravitational potential energy is zero must be chosen for each problem

✓ The choice is arbitrary since the change in the potential energy is the important quantity

✓ Choose a convenient location for the zero reference height

often the Earth's surface

may be some other point suggested by the problem

✓ Once the position is chosen, it must remain fixed for the entire problem

Extended Work-Energy Theorem

- We denote the total mechanical energy by:

$$\boldsymbol{E = KE + PE}$$

If the gravitational force is the only force acting on an object: Work done by the force ...

$$W = -\Delta PE$$

And $$W = \Delta KE$$

$$=> \Delta KE = -\Delta PE$$

$$\boldsymbol{KE_f - KE_i = PE_i - PE_f}$$

- Finally: $$\boldsymbol{KE_f + PE_f = PE_i + KE_i}$$

The total mechanical energy is conserved and remains the same at all times.

- in case of g = const: near surface of the Earth

$$\boldsymbol{\frac{1}{2}mv_f^2 + mgy_f = \frac{1}{2}mv_i^2 + mgy_i}$$

Problem-Solving Strategy

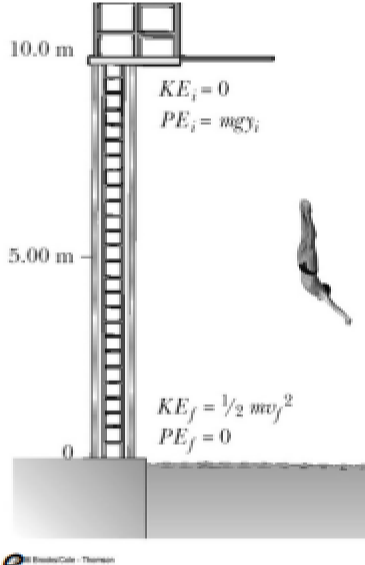
- Define the system
- Select the location of zero gravitational potential energy
  - Do *not* change this location while solving the problem
- Identify two points the object of interest moves between
  - One point should be where information is given
  - The other point should be where you want to find out something

Example 1. Platform Diver

- A diver of mass m drops from a board 10.0 m above the water's surface. Neglect air resistance.

(a) Find is speed 5.0 m above the water surface.

(b) Find his speed as he hits the water.



Solution:

(a) Find his speed 5.0 m above the water surface

$$\frac{1}{2}mv_i^2 + mgy_i = \frac{1}{2}mv_f^2 + mgy_f$$

$$0 + gy_i = \frac{1}{2}v_f^2 + mgy_f$$

$$v_f = \sqrt{2g(y_i - y_f)}$$

$$= \sqrt{2(9.81\, m/s^2)(10m - 5m)} \approx \mathbf{9.9\, m/s}$$

(b) Find his speed as he hits the water

$$0 + mgy_i = \frac{1}{2}mv_f^2 + 0 \quad => \quad \boldsymbol{v_f = \sqrt{2gy_i} = 14\, m/s}$$

Geosynchronous Orbit

- From a telecommunications point of view, it's advantageous for satellites to remain at the same location relative to a location on the Earth. This can occur only if the satellite's orbital period is the same as the Earth's period of rotation, 24 h.
- (a) At what distance from the center of the Earth can this geosynchronous orbit be found?
- (b) What's the orbital speed of the satellite?

$$T = \sqrt{\frac{4\pi^2}{GM_E}a^3} = 24\ \mathrm{h} = 86400\ \mathrm{s}$$

$$a = (GM_E T^2/4\pi^2)^{1/3} = [(6.67\mathrm{e}-11)(5.97\mathrm{e}24)(86400\ \mathrm{s})^2/4\pi^2]^{1/3}$$
$$= 41500\mathrm{km}$$

Chapter 5. Energy (cont.)

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7) Conservative and Non-conservative For
8) Conservation of Energy

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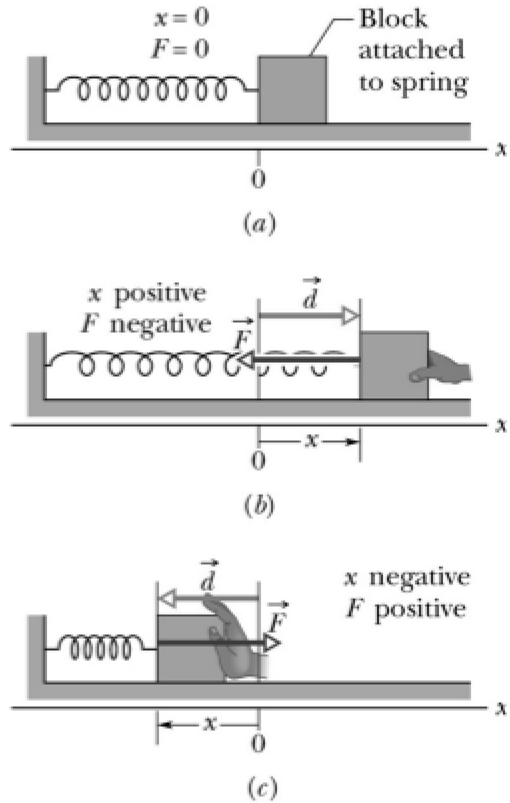
5.6. Elastic potential energy: PE in a Spring

Spring Force

- Involves the *spring constant, k*
- Hooke's Law gives the force

$$\vec{F} = -k\vec{d}$$



- F is in the opposite direction of displacement d, always back towards the equilibrium point.
- k depends on how the spring was formed, the material it is made from, thickness of the wire, etc.
- Unit of k: N/m.

5.6. Elastic potential energy: PE in a Spring

- Work done by the spring

$$W_s = \int_{x_i}^{x_f}(-kx)dx = \frac{1}{2}kx_i^2 - \frac{1}{2}kx_f^2$$

$$W_s = PE_{s/i} - PE_{s/f}$$

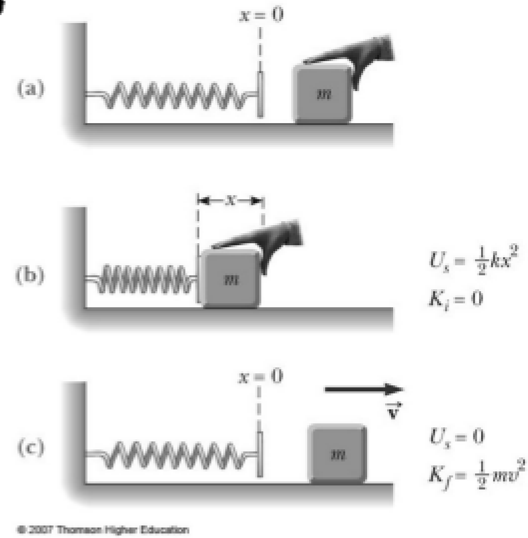
(i: initial; f: final)

- Elastic Potential Energy:

$$PE_s = \frac{1}{2}kx^2$$

SI unit: Joule (J)

related to the work required to compress/extend a spring from its equilibrium position to some final, arbitrary, position *x*



Extended Work-Energy Theorem

- The work-energy theorem can be extended to include potential energy:

$$\boxed{W_{net} = KE_f - KE_i = \Delta KE}$$

$$W_{gravity} = PE_i - PE_f \qquad\qquad W_s = PE_{si} - PE_{sf}$$

- If we include gravitational force and spring force, then

$$W_{net} = W_{gravity} + W_s$$

$$(KE_f - KE_i) + (PE_f - PE_i) + (PE_{sf} - PE_{si}) = 0$$

$$\boxed{\boldsymbol{KE_f + PE_f + PE_{sf} = PE_i + KE_i + KE_{si}}}$$

=> Conservation of Energy

Extended Work-Energy Theorem

- We denote the total mechanical energy by

$$\boldsymbol{E = KE + PE + PE_s}$$

- Since: $(\boldsymbol{KE + PE + PE_s})_f = (\boldsymbol{KE + PE + PE_s})_i$
- The total mechanical energy is conserved and remains the same at all times (if ... only $\underbrace{\text{conservative forces}}$ acting on the object)

$$\boxed{\frac{1}{2}mv_i^2 + mgy_i + \frac{1}{2}kx_i^2 = \frac{1}{2}mv_f^2 + mgy_f + \frac{1}{2}kx_f^2}$$

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7) Conservative forces and Non-conservative forces

- **Conservative forces**

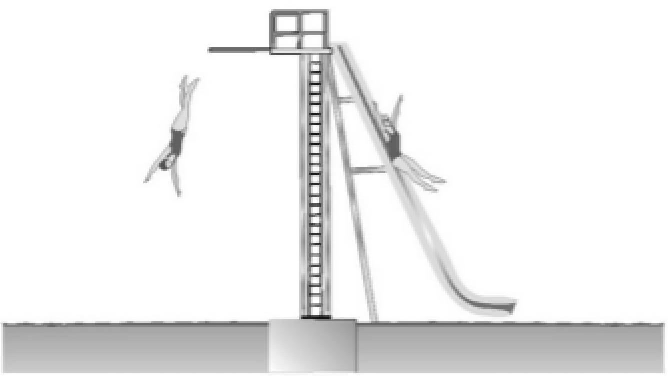
  - Work and energy associated with the force can be recovered

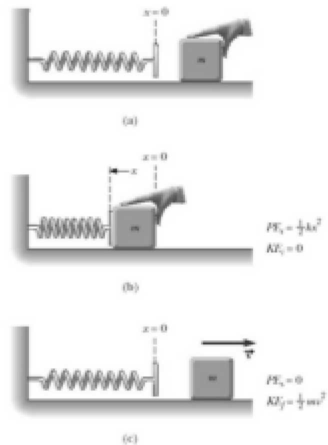
  - Examples: Gravity, Spring Force, EM forces

- **Nonconservative forces**

  - The forces are generally dissipative and work done against it cannot easily be recovered

  - Examples: Kinetic friction, air drag forces, normal forces, tension forces, applied forces …





Conservative Forces

- A force is **conservative** if the work it does on an object moving between two points is **independent** of the path the objects take between the points

✓The work depends only upon the initial and final positions of the object

✓Any conservative force can have a potential energy function associated with it

✓Work done by gravity:

$$W_g = PE_i - PE_f = mgy_i - mgy_f$$

✓Work done by spring force:

$$\boldsymbol{W_s = PE_{si} - PE_{sf} = \frac{1}{2}kx_i^2 - \frac{1}{2}kx_f^2}$$

<u>Nonconservative Forces</u>

- A force is **nonconservative** if the work it does on an object **depends on the path** taken by the object between its final and starting points.

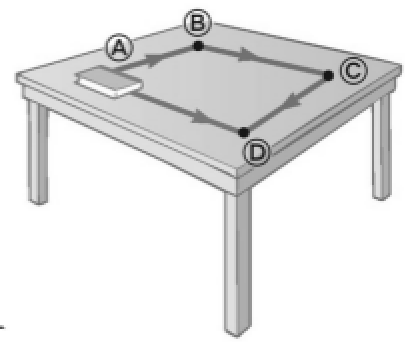
✓ The work depends upon the movement path

✓ For a non-conservative force, potential energy can NOT be defined

✓ Work done by a nonconservative force

$$W_{nc} = \sum \vec{F} \cdot \vec{d} = -f_k d + \sum W_{otherforces}$$

✓ It is generally dissipative. The dispersal of energy takes the form of heat or sound



Extended Work-Energy Theorem

- The work-energy theorem can be written as:

$$W_{net} = KE_f - KE_i = \Delta KE$$

$$W_{net} = W_{nc} + W_c$$

  - W_{nc} represents the work done by nonconservative forces
  - W_c represents the work done by conservative forces
- Any work done by conservative forces can be accounted for by changes in potential energy: $W_c = PE_i - PE_f$

Gravity work: $W_g = PE_i - PE_f = mgy_i - mgy_f$

Spring force work: $W_s = PE_i - PE_f = \frac{1}{2}kx_i^2 - \frac{1}{2}kx_f^2$

Extended Work-Energy Theorem

- Any work done by conservative forces can be accounted for by changes in potential energy

$$W_c = PE_i - PE_f = -(PE_f - PE_i) = -\Delta PE$$

$$W_{nc} = \Delta KE + \Delta PE = (KE_f - KE_i) + (PE_f - PE_i)$$

$$W_{nc} = (KE_f + PE_f) - (KE_i + PE_i)$$

- Mechanical energy includes kinetic and potential energy

$$E = KE + PE = KE + PE_g + PE_s = \frac{1}{2}mv^2 + mgy + \frac{1}{2}kx^2$$

$$\boxed{W_{nc} = E_f - E_i}$$

Problem-Solving Strategy

- Define the system to see if it includes non-conservative forces (especially friction, drag force ...)
- Without non-conservative forces

$$\frac{1}{2}mv_f^2 + mgy_f + \frac{1}{2}kx_f^2 = \frac{1}{2}mv_i^2 + mgy_i + \frac{1}{2}kx_i^2$$

- With non-conservative forces:

$$W_{nc} = (KE_f + PE_f) - (KE_i + PE_i)$$

$$W_{nc} = (\frac{1}{2}mv_f^2 + mgy_f + \frac{1}{2}kx_f^2) - (\frac{1}{2}mv_i^2 + mgy_i + \frac{1}{2}kx_i^2)$$

- Select the location of zero potential energy
  - Do *not* change this location while solving the problem
- Identify two points the object of interest moves between
  - One point should be where information is given
  - The other point should be where you want to find out something

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8) Conservation of Energy

- ***Energy is conserved***
  - This means that energy cannot be created nor destroyed
  - If the total amount of energy in a system changes, it can only be due to the fact that energy has crossed the boundary of the system by some method of energy transfer

Ways to Transfer Energy Into or Out of A System

- ***Work*** – transfers by applying a force and causing a displacement of the point of application of the force
- ***Mechanical Waves*** – allow a disturbance to propagate through a medium
- ***Heat*** – is driven by a temperature difference between two regions in space
- ***Matter Transfer*** – matter physically crosses the boundary of the system, carrying energy with it
- **Electrical Transmission** – transfer is by electric current
- **Electromagnetic Radiation** – energy is transferred by electromagnetic waves