# Recap: Artificial Satellites

- Kepler's 3rd Law: $T^2 \propto r^3$
- Thus the lower the altitude, the shorter the period.
- Example: Sputnik (1958)

  Launched into a very low altitude orbit of ~ 270 km.

  => T = 90 min (1.5 hrs to orbit Earth)

- Example: Geosynchronous Orbit
- Orbital period, T = 24 hours
- Permits satellites to remain "stationary" over a given equatorial longitude.

  => r = 42,000 km (to center Earth)

  i.e. altitude $\approx 7\ R_e$

  (compared with 60 $R_e$ for Moon.)

# Orbital Velocity

- By equating the centripetal force to the gravitational attraction force we can determine orbital speed ($v_{or}$).

**For circular motion:**

**Centripetal force = gravitational force ($F_C = F_G$)**

$$\frac{m\,v_{or}^2}{r} = \frac{G\,M\,m}{r^2}$$

**M = planet's mass**
**m = satellite's mass**
**M » m**

$$v_{or} = \sqrt{\frac{G\,M}{r}}$$

**Results:**

- **Any satellite regardless of its mass (provided M » m) will move in a circular orbit or radius r and velocity $v_{or}$.**

- **The larger the orbital altitude, the <u>lower</u> the required tangential velocity!**

**Example:** Low Earth orbit (LEO): altitude 600 km

$$v_{or} = \sqrt{\frac{G\,M}{r}} = \sqrt{\frac{\left(6.67\times10^{-11}\right)\times\left(5.98\times10^{-24}\right)}{6970\times10^{3}}}$$

$= 7.6$ km/s (or $27\times10^{3}$ km/hr)

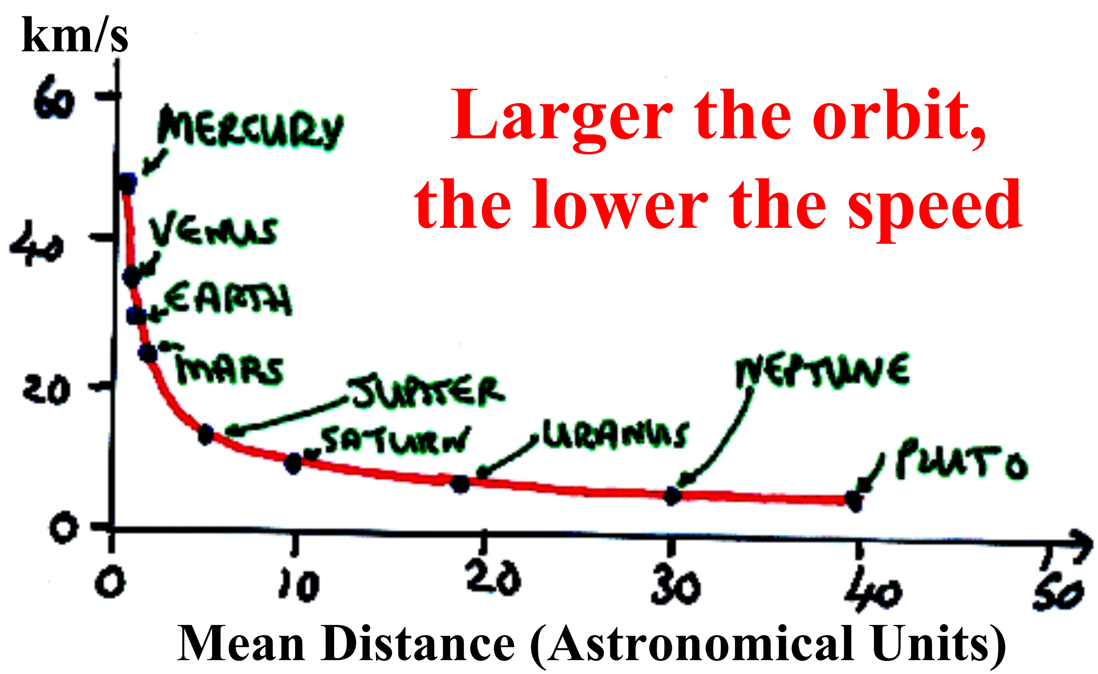
Note: At lunar orbit (~400,000 km) orbital speed ~ 1 km/s

**Planetary Orbital Velocity:**

$$\mathbf{v_{or}} = \sqrt{\frac{\mathbf{GM}}{\mathbf{r}}}$$

M = mass of the Sun

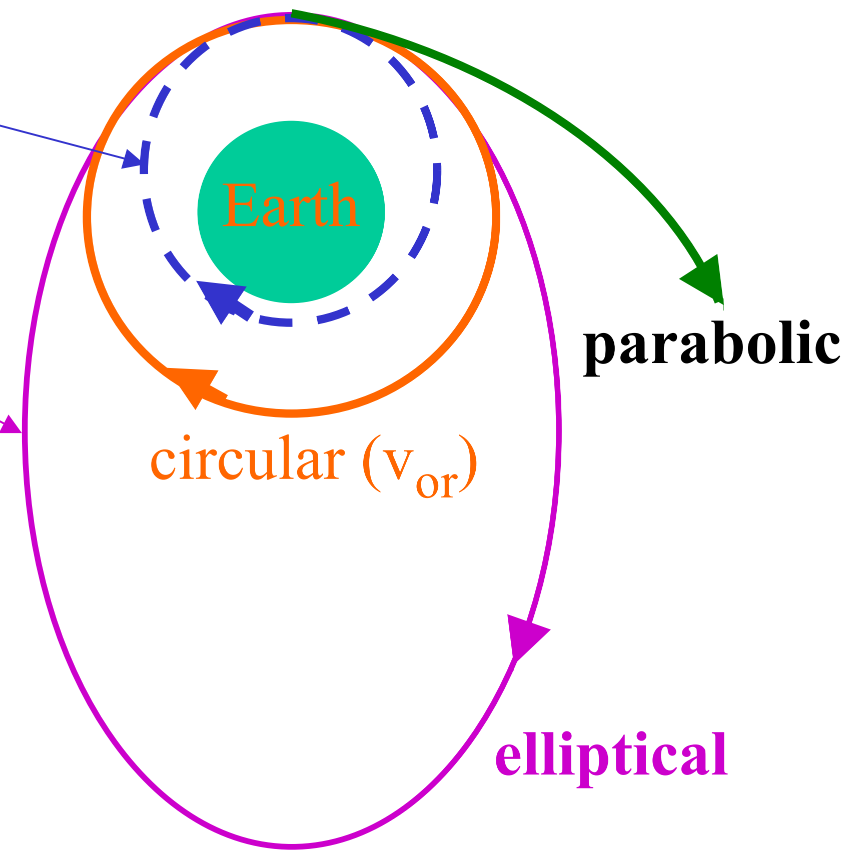
**Larger the orbit, the lower the speed**



# How to Achieve Orbit

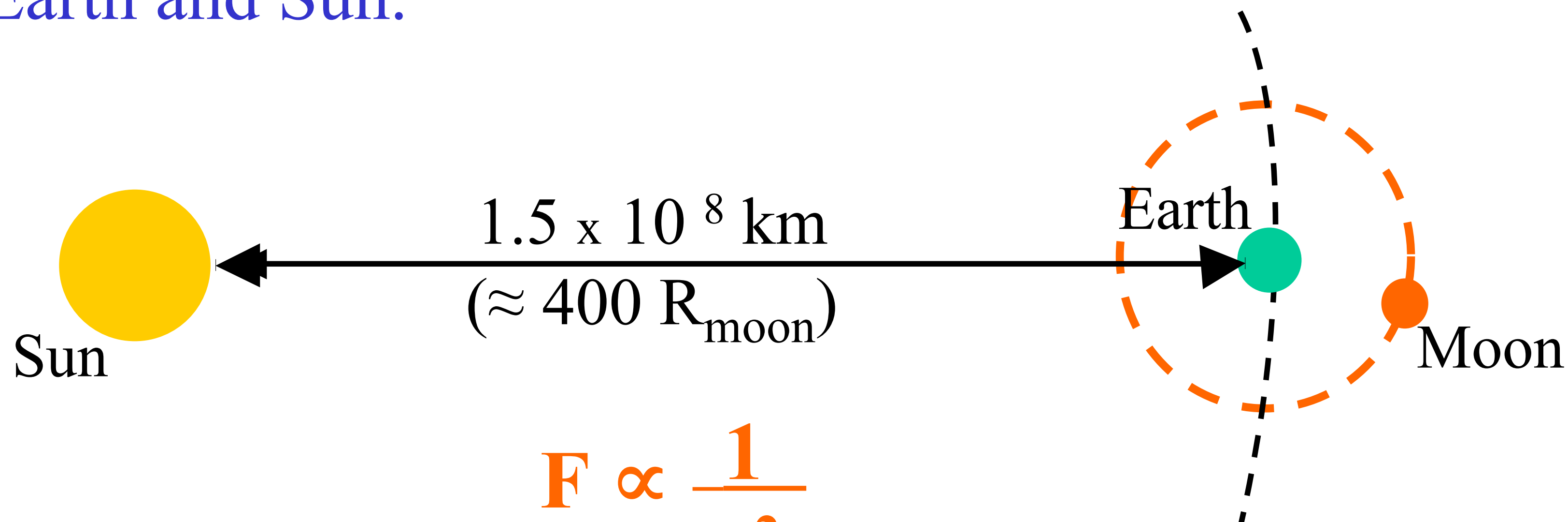
- Launch vehicle initially rises vertically (minimum air drag).
- Gradually rolls over and on separation of payload is moving tangentially at speed $v_{or}$ produces circular orbit.

  - If speed less than $v_{or}$, craft will descend to Earth in an (decaying) elliptical orbits.
  - If speed greater than $v_{or}$ it will ascend into a large elliptical orbit.
  - If speed greater than $\sqrt{2v_{or}}$ it will escape earths gravity on parabolic orbit!



# Lunar Orbit

- Not a simple ellipse… due to gravitational force of Earth and Sun.



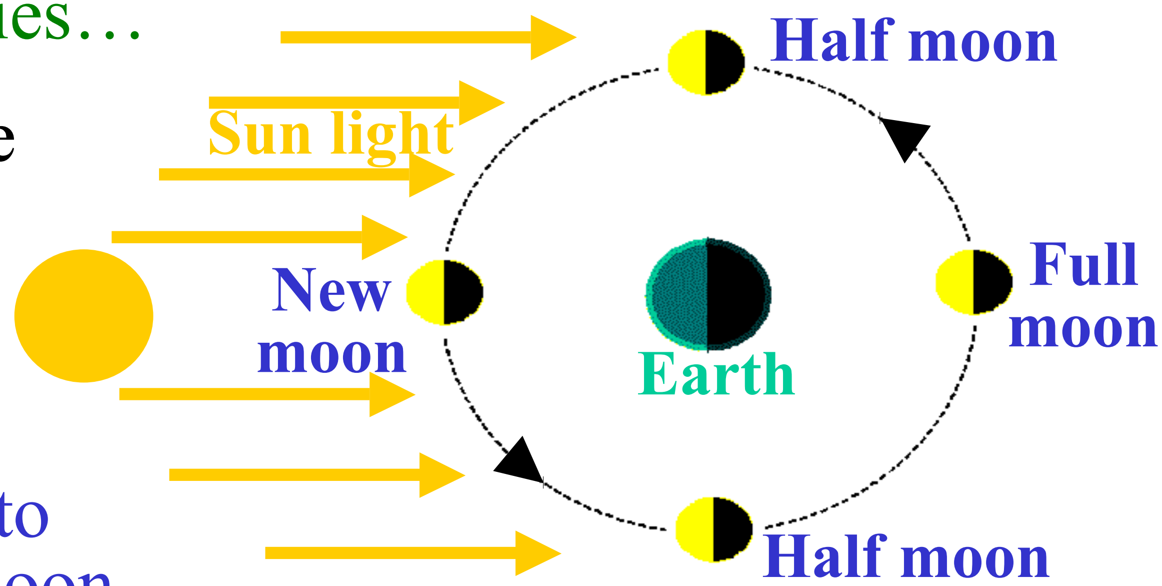

$$\mathbf{F \propto \frac{1}{r^2}}$$

- Gravitational attraction between Earth and Moon provides **centripetal acceleration** for orbit.

- **Sun's** gravitation **distorts** lunar **orbital ellipse**. (Orbit oscillates about true elliptical path.)

# Properties of the Moon

- The only satellite Newton could study and played a key role in his discoveries…
- Phases known since prehistoric times…
- Moonlight is reflected sunlight.
- Phases simply due to geometry of sun, moon and Earth.




Phases repeat every 27.3 days (lunar orbit).

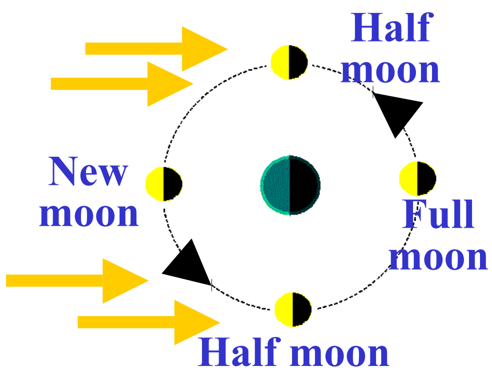
**Full moon:**

- Moon on opposite side of Earth from Sun.
- Fully illuminated disk.
- Rises at sunset and sets at sunrise (due to Earth's 24 hr rotation).
- **Lunar eclipse** only during full moon.

# Properties of the Moon (cont'd)

- At other times during moon's orbit of Earth, we see only a part of illuminated disk.

**New moon:**




- Moon on same side of Earth as the Sun.
- Essentially invisible (crescent moons seen either side of New moon).
- Rises at sunrise and sets at sunset (i.e. up all day).
- **Solar eclipse** condition.

- When moon is in-between full and new phase, it can often be **seen during daylight** too.
- Example: half moon rises at noon and sets at midnight (and vice versa).
- Under good observing conditions (at sunset or sunrise) you can see dark parts of moon illuminated by Earthshine!

# Energy (Chapter 6)

## What is energy?

- Energy comes in many forms:

| | | |
|---|---|---|
| Mechanical | Electrical | Chemical |
| Atomic | Thermal | Acoustic… |

- Energy can be converted from one form to another…

**Example**: A car converts chemical energy into mechanical (motion) energy and heat.

**Question**: How can a "system" change its energy?

**Answer**: By doing **"work"** on it!

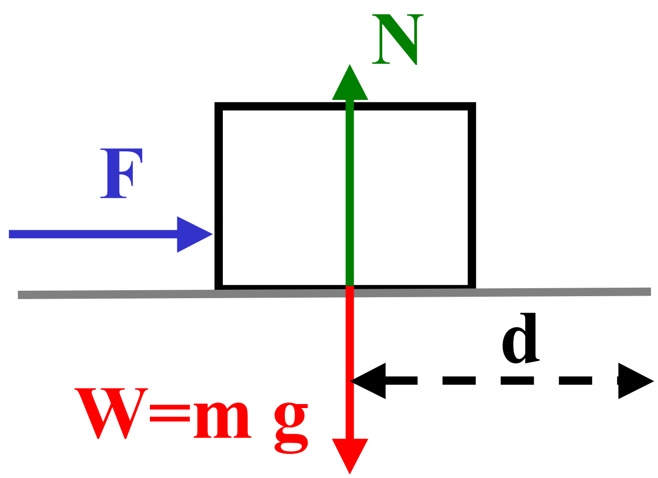
# What is work and what does it depend on?

- When you push your car or lift a box, you are doing work (against friction or against gravity).
- When we do work on a system, we raise its energy (eg. lift a pendulum bob).
- This excess energy can then be used for motion (eg. starting a pendulum) or it can be stored (eg. in a battery) for later use.
- **Example**: When you lift a book up and put it on a high shelf, you are doing work against gravity and increasing the potential energy of the book.
- **Work: - Depends on strength of applied force.**

  **- Distance object is moved by the force.**

**Work = Force x Distance**

**= F x d**




**Units: Work = N.m or Joules (J)**

- **1 Joule is the work expended by an applied force of 1 Newton acting over a distance of 1 meter.**
- **Work is the same as energy (work is mechanical energy).**
- **The work done by a given force is the product of the component of force acting along the line of motion of object, multiplied by the distance moved under that force.**

**Thus the further you move an object or larger the applied force, the larger the work done.**

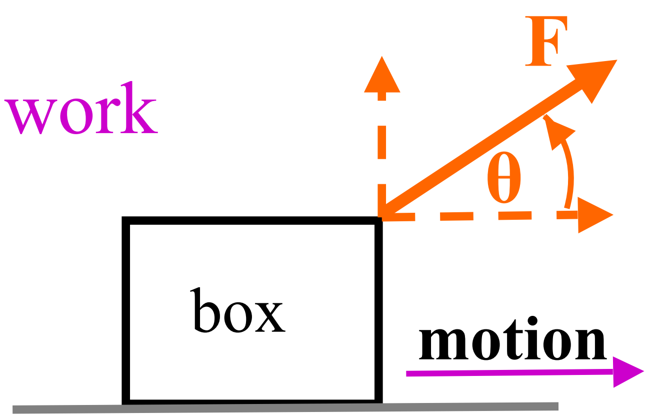
Example: What is the work done to move a box by 10 m using a force of 100 N?

$$\mathbf{W = F \times d} = 100 \times 10 = \mathbf{1{,}000\ J}$$

i.e. 1000 J of energy are expended by you and used to raise the energy of box and its surroundings by 1,000 J.

- In general we use the component of applied force causing motion, to find work done:

e.g. $\mathbf{W = F \cos\theta \,.\, d}$

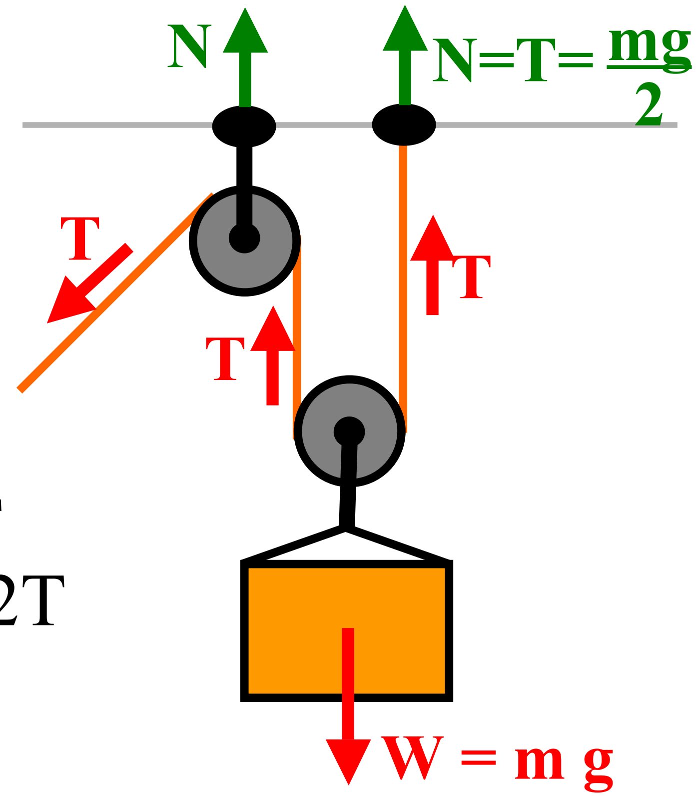



- **No work is done by forces acting perpendicular to the motion. (e.g. by box weight or normal force for horizontal motion).**

# Simple machines:

e.g. a lever or a pulley

Mechanical devices designed to multiply effects of applied force.




In this example a tension force of 1T can be used to lift a weight equal to 2T = W = m g.

**Key**: The **work done** is the same for both the **lifter** and the **object lifted** as **lifter** needs to **move 2d** to **lift object** up **1d** in height.

i.e. **Work output = Work input**

(assuming no losses due to friction etc.)

## Power and Work

- The larger the applied force (F) the quicker we will move the object - e.g. a car accelerating (as F =m.a).
- The rate at which work is done on a system depends on its power – more powerful engines can accelerate a car to a given velocity in a shorter time.

❖ **Power is the rate of doing work:**

$$P = \frac{\text{Work}}{\text{Time}} = \frac{W}{T} = \frac{\text{Force} \times \text{Distance}}{\text{Time}}$$

- Units: Power = J / s = Watt (W)

**Example:** What is the power required to move the 50 kg box 10 m using a force of 100 N in (a) 10s and (b) 2s.

$$\text{Power} = \frac{F \times d}{t}$$

(a) $P = \frac{100 \times 10}{10} = 100\ \text{W}$

(b) $P = \frac{100 \times 10}{2} = 500\ \text{W}$

# Summary

1. **Work** is the applied force times the distance moved (in direction of applied force). Units = **Joules**
2. **Work output** cannot exceed **work input** (but forces can be multiplied at expense of distance moved).
3. **Power** is the rate of doing work – the faster its done, the greater the power. Units = **Watts** (1 hp = 746 W)
4. **Work is energy** and doing work on a system **increases** the **total energy** of the system.

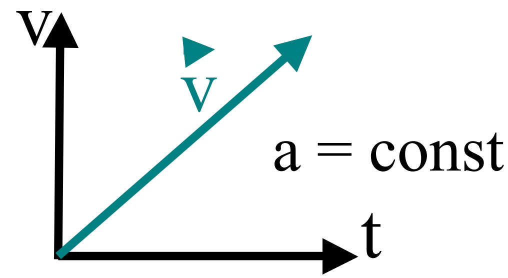
**Question**: How does "**doing work**" on a system raise its energy?

Two types of energy transfer can occur:

1. **Kinetic energy** (due to a change in its motion)
2. **Potential energy** (due to its change in position while acted upon by a force)

# Kinetic Energy

- An applied force (F) will cause a body of mass (m) to accelerate ($F = m.a$) and hence its velocity will increase uniformly with time.
- Doing work on an object in this manner causes its kinetic energy to increase i.e.




- In time as the velocity increases you need to run faster to apply the force.

  i.e. In equal time intervals you will move larger distances as your velocity increases ($d \propto v^2$).
- Thus work done is proportional to **velocity squared**.

❖ **Work done = Change in kinetic energy**

$$W = KE = \tfrac{1}{2}\, m.v^2 \quad \text{(Joules)}$$

- Kinetic energy is the result of an object's motion and is proportional to its velocity squared.
- **Note:** Under constant acceleration the KE (and work done) increases rapidly with time and hence the **power** needed increases with time.

**Example:** Compare energy gained by a system by doing work on it with its resultant KE. (Box at rest, mass = 50 kg, applied force = 100N (net force), distance moved = 10 m.)

**Work done** $W = F \cdot D = 100 \times 10 = 1{,}000$ J

**KE = ½ m.v²** but 'v', is unknown, and so are 't' and 'a'.

So, use 1. $F = m.a$ or $a = \frac{F}{m} = \frac{100}{50} = 2 \text{ m/s}^2$

2. $d = \frac{1}{2} a.t^2$ or $t = \sqrt{\frac{2d}{a}} = \sqrt{\frac{2 \times 10}{2}} = \sqrt{10}$ sec

3. $v = a.t$ or $v = 2\sqrt{10}$ m/s

Thus, $KE = \frac{1}{2} m.v^2 = \frac{1}{2} \times 50 \times (2\sqrt{10})^2 = 1{,}000$ J

**Conclusion: The work done equals the change (increase) in Kinetic Energy.**

# Energy Loss "Negative Work"

- To reduce the KE of an object (e.g. a car), we also need to perform work, called "Negative Work".
- In this case work is done by friction when braking. (Brake drums heat up or tires skid.)
- Negative work **reduces energy** of a system.

**Example:** Stopping distance for a car, etc…

Kinetic energy of a vehicle is proportional to $v^2$ - if speed is doubled, the KE is quadrupled!

i.e. A bus traveling at 80 km/hr has four times as much kinetic energy than one at 40 km/hr.

Doubling the speed requires four times as much "negative work" to stop it.

**Result:** Stopping distance is around **four times longer** for the 80 km/hr vehicle!!! (assuming a constant frictional force).

**Summary: The KE gained or lost by an object is equal to the work done by the net force.**

# Potential Energy

**Question:** What happens to the work done when e.g. lifting a box onto a table?

If we lift it so that our applied force is equal and opposite to its weight force, there will be no acceleration and no change in its Kinetic Energy. (F = m.g)

Yet work is clearly done…

**Answer:** The work done increases the **gravitational potential energy** of the box.

- Potential energy is **stored energy** (for use later) e.g. a rock poised to fall…
- Potential energy involves changing the position of an object that is being acted upon by a specific force (e.g. gravity).
- **Gravitational potential energy (PE) equals work done to move object a vertical distance (h).**

**PE = W = F . d**

**PE = m.g.h (units = Joules)**

- Thus, the further we move an object away from the center of the Earth, the greater its potential energy.
- And, the larger the height change, the larger the change in PE.

**Example:** What is PE of a 50kg box lifted 10m?

$$PE = m.g.h = 50 \times 9.8 \times 10 = 4{,}900\ J$$

- If height is doubled, PE is doubled…
- Other kinds of PE involving other forces also exist (eg. springs).

**Summary:**

- **Potential energy is stored energy associated with an object's position rather than its motion.**
- **The "system" is poised to release energy converting it to KE or work done on another system.**
- **Potential energy can result from work done against a variety of <u>conservative forces</u> eg. gravity and springs.**