

# • **PROGRAM OF “PHYSICS”**

---

**Lecturer: Dr. DO Xuan Hoi**

**Room A1. 503**

**E-mail : [dxhoi@hcmiu.edu.vn](mailto:dxhoi@hcmiu.edu.vn)**

# **PHYSICS I**

## **(General Mechanics)**

### **02 credits (30 periods)**

#### **Chapter 1 Bases of Kinematics**

- Motion in One Dimension
- Motion in Two Dimensions

#### **Chapter 2 The Laws of Motion**

#### **Chapter 3 Work and Mechanical Energy**

#### **Chapter 4 Linear Momentum and Collisions**

#### **Chapter 5 Rotation of a Rigid Object About a Fixed Axis**

#### **Chapter 6 Static Equilibrium**

#### **Chapter 7 Universal Gravitation**

# **PHYSICS I**

## **Chapter 7**

### **Universal Gravitation**

Newton's Law of Universal Gravitation

Kepler's Laws

Gravitational Potential Energy

# 1. Newton's Law of Universal Gravitation

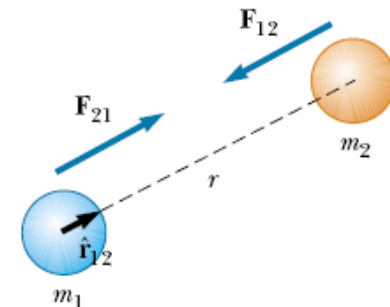
- The Law: "Every particle in the Universe attracts every other particle with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between them."

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

$$G = 6.673 \times 10^{-11} \text{ Nm}^2/\text{kg}^2$$



$$\vec{F}_{12} = -G \frac{m_1 m_2}{r^2} \vec{r}_{12} = -G \frac{m_1 m_2}{r^3} \vec{r}$$



## • Free-Fall Acceleration

The force acting on a freely falling object of mass  $m$  near the Earth's surface. Newton's second law:

$$F = ma \equiv mg = F_g = G \frac{M_E m}{R_E^2}$$

( $M_E$ : Earth's mass;  $R_E$ : Earth's radius)

$$\longrightarrow g = G \frac{M_E}{R_E^2} \approx 9.81 \text{ m} / \text{s}^2$$

Object of mass  $m$  located a distance  $h$  above the Earth's surface or a distance  $r$  from the Earth's center:

$$\longrightarrow g' = G \frac{M_E}{(R_E + h)^2}$$

## ***EXAMPLE 1***

Two objects attract each other with a gravitational force of magnitude  $1.00 \times 10^{-8}$  N when separated by 20.0 cm. If the total mass of the two objects is 5.00 kg, what is the mass of each?

$$F_g = G \frac{m_1 m_2}{r^2} = 6.673 \times 10^{-11} \frac{m_1 m_2}{(0.20)^2} = 1.00 \times 10^{-8}$$

$$m_1 m_2 = 6.00$$

$$m_1 + m_2 = 5.00 \text{ kg}$$

$$m_1 = 2.00 \text{ kg}; m_2 = 3.00 \text{ kg}$$

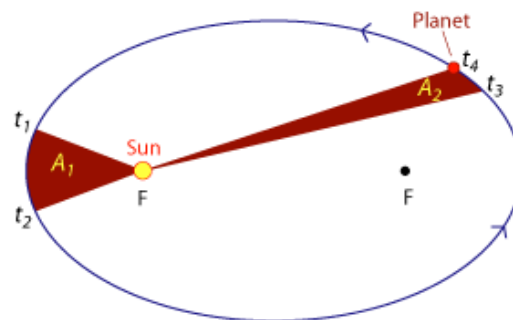
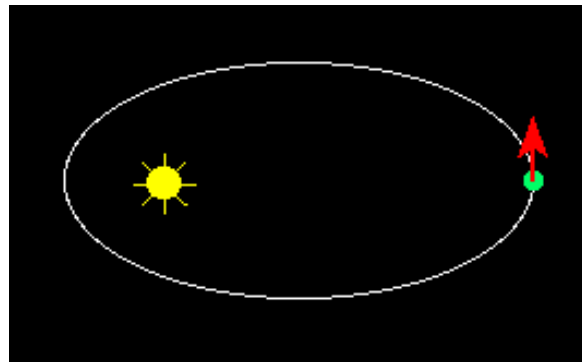
$$m_1 = 3.00 \text{ kg}; m_2 = 2.00 \text{ kg}$$

## 2. Kepler's laws

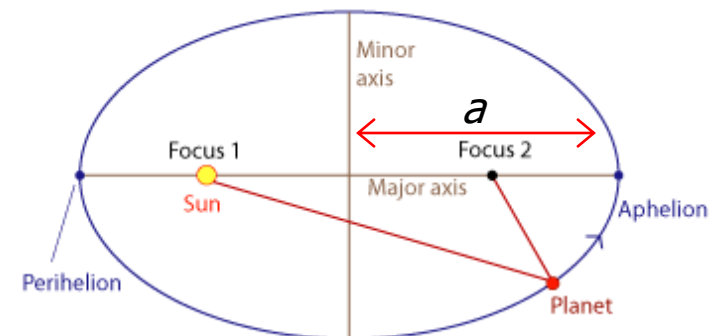
1. All planets move in elliptical orbits with the Sun at one focal point.
2. The radius vector drawn from the Sun to a planet sweeps out equal areas in equal time intervals.
3. The square of the orbital period of any planet is proportional to the cube of the semimajor axis of the elliptical orbit.



$T$  : period of revolution,  $a$  : semimajor axis  $\longrightarrow T^2 = K_s a^3$

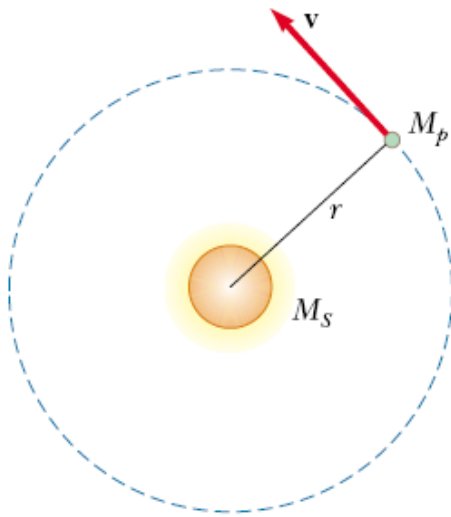


Kepler's Second Law:  
Law of Equal Areas  
(greatly exaggerated)



An elliptical orbit of a planet  
(greatly exaggerated)

**CIRCULAR ORBIT** : A planet of mass  $M_p$  moving around the Sun of mass  $M_S$  in a circular orbit



$$\frac{GM_S M_p}{r^2} = \frac{M_p v^2}{r}$$

$$\frac{GM_S}{r^2} = \frac{(2\pi r/T)^2}{r}$$

$$T^2 = \left( \frac{4\pi^2}{GM_S} \right) r^3 = K_S r^3$$



## ***EXAMPLE 2***

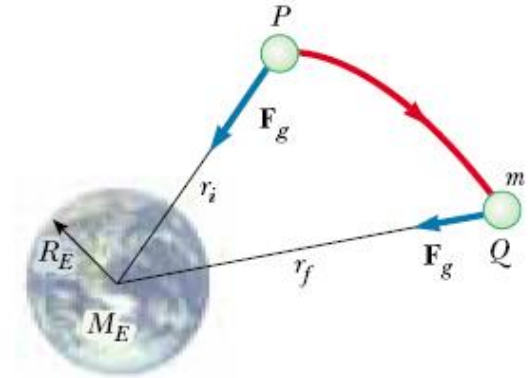
Calculate the mass of the Sun using the fact that the period of the Earth's orbit around the Sun is  $3.156 \times 10^7$  s and its distance from the Sun is  $1.496 \times 10^{11}$  m.

$$M_S = \frac{4\pi^2 r^3}{GT^2} = \frac{4\pi^2 (1.496 \times 10^{11} \text{ m})^3}{(6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2) (3.156 \times 10^7 \text{ s})^2}$$
$$= 1.99 \times 10^{30} \text{ kg}$$

### 3. Gravitational Potential Energy

$$F = -\frac{dU}{dr}$$

$$dU = -Fdr = -\left[-G\frac{m_1m_2}{r^2}\right]dr$$



$$U_f - U_i = \int_{U_i}^{U_f} dU = \int_{r_i}^{r_f} -G\frac{m_1m_2}{r^2}dr = Gm_1m_2 \int_{r_i}^{r_f} -\frac{dr}{r^2}$$

$$U_f - U_i = -Gm_1m_2 \left[ \frac{1}{r_f} - \frac{1}{r_i} \right]$$

We put :

$$U_f = -G\frac{m_1m_2}{r_f} ; \quad U_i = -G\frac{m_1m_2}{r_i}$$

In general:

$$U = -G\frac{m_1m_2}{r}$$

## To compare:

- Gravitational force near the Earth's surface:  $F = mg$

Gravitational potential near the Earth's surface:  $U = -mgx$

- Elastic force :  $F = -kx$

Elastic potential:  $U = \frac{1}{2} kx^2$

- Gravitational force :  $F_g = G \frac{m_1 m_2}{r^2}$

Gravitational potential :  $U = -G \frac{m_1 m_2}{r}$

- Coulomb force :  $F_c = K \frac{q_1 q_2}{r^2}$

Gravitational potential :  $U_c = -K \frac{q_1 q_2}{r}$

**General formula:**

$$F = -\frac{dU}{dr}$$

$$\vec{F} = -\text{grad}U \equiv -\nabla U$$

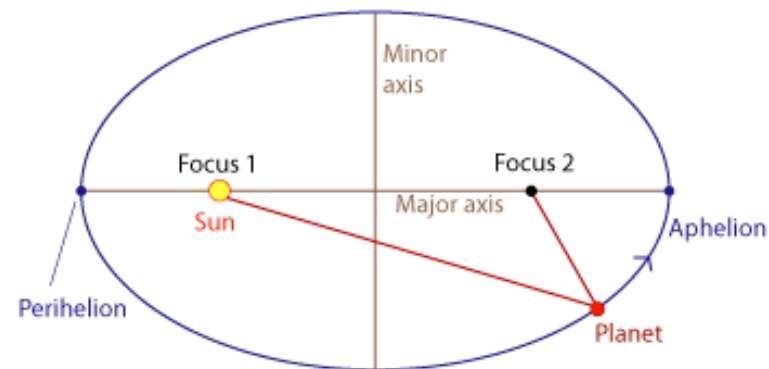
### ***EXAMPLE 3***

As Mars orbits the sun in its elliptical orbit, its distance of closest approach to the center of the sun (at perihelion) is  $2.067 \times 10^{11}$  m, and its maximum distance from the center of the sun (at aphelion) is  $2.492 \times 10^{11}$  m. If the orbital speed of Mars at aphelion is  $2.198 \times 10^4$  m/s, what is its orbital speed at perihelion? (You can ignore the influence of the other planets.)

Apply conservation of energy:

$$\frac{1}{2}m_M v_a^2 - \frac{GM_S m_M}{r_a} = \frac{1}{2}m_M v_p^2 - \frac{GM_S m_M}{r_p}$$

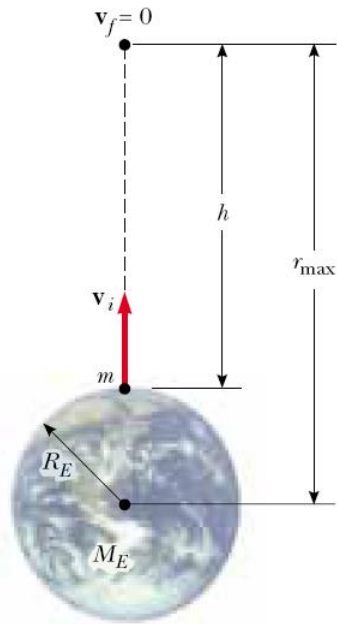
$$v_p = \sqrt{v_a^2 - 2GM_S \left( \frac{1}{r_a} - \frac{1}{r_p} \right)} = 2.650 \times 10^4 \text{ m/s.}$$



*An elliptical orbit of a planet  
(greatly exaggerated)*

## EXAMPLE 4 Escape Speed

Escape speed: The minimum speed the object must have at the Earth's surface in order to escape from the influence of the Earth's gravitational field.



$$\frac{1}{2}mv_i^2 - \frac{GM_E m}{R_E} = -\frac{GM_E m}{r_{\max}}$$

$$v_i^2 = 2GM_E \left( \frac{1}{R_E} - \frac{1}{r_{\max}} \right)$$

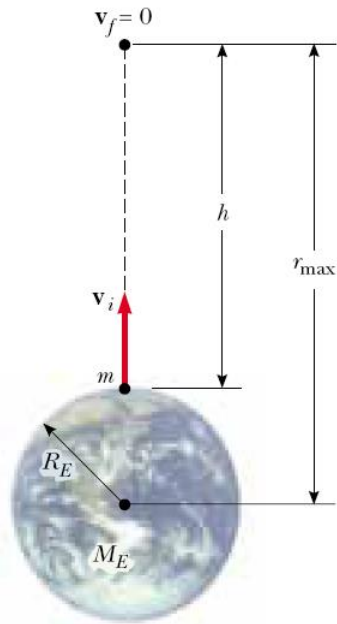
$$h = r_{\max} - R_E$$

$$r_{\max} \rightarrow \infty \quad v_i = v_{\text{esc}}$$

$$v_{\text{esc}} = \sqrt{\frac{2GM_E}{R_E}}$$

## **EXAMPLE 4** Escape Speed

Escape speed: The minimum speed the object must have at the Earth's surface in order to escape from the influence of the Earth's gravitational field.



$$\begin{aligned} v_{\text{esc}} &= \sqrt{\frac{2GM_E}{R_E}} \\ &= \sqrt{\frac{2(6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2)(5.98 \times 10^{24} \text{ kg})}{6.37 \times 10^6 \text{ m}}} \\ &= 1.12 \times 10^4 \text{ m/s} \end{aligned}$$