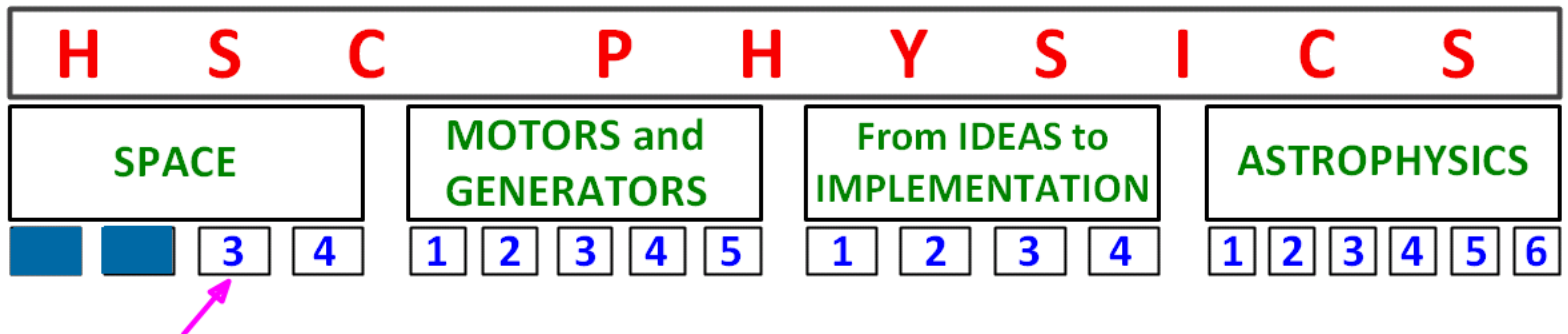


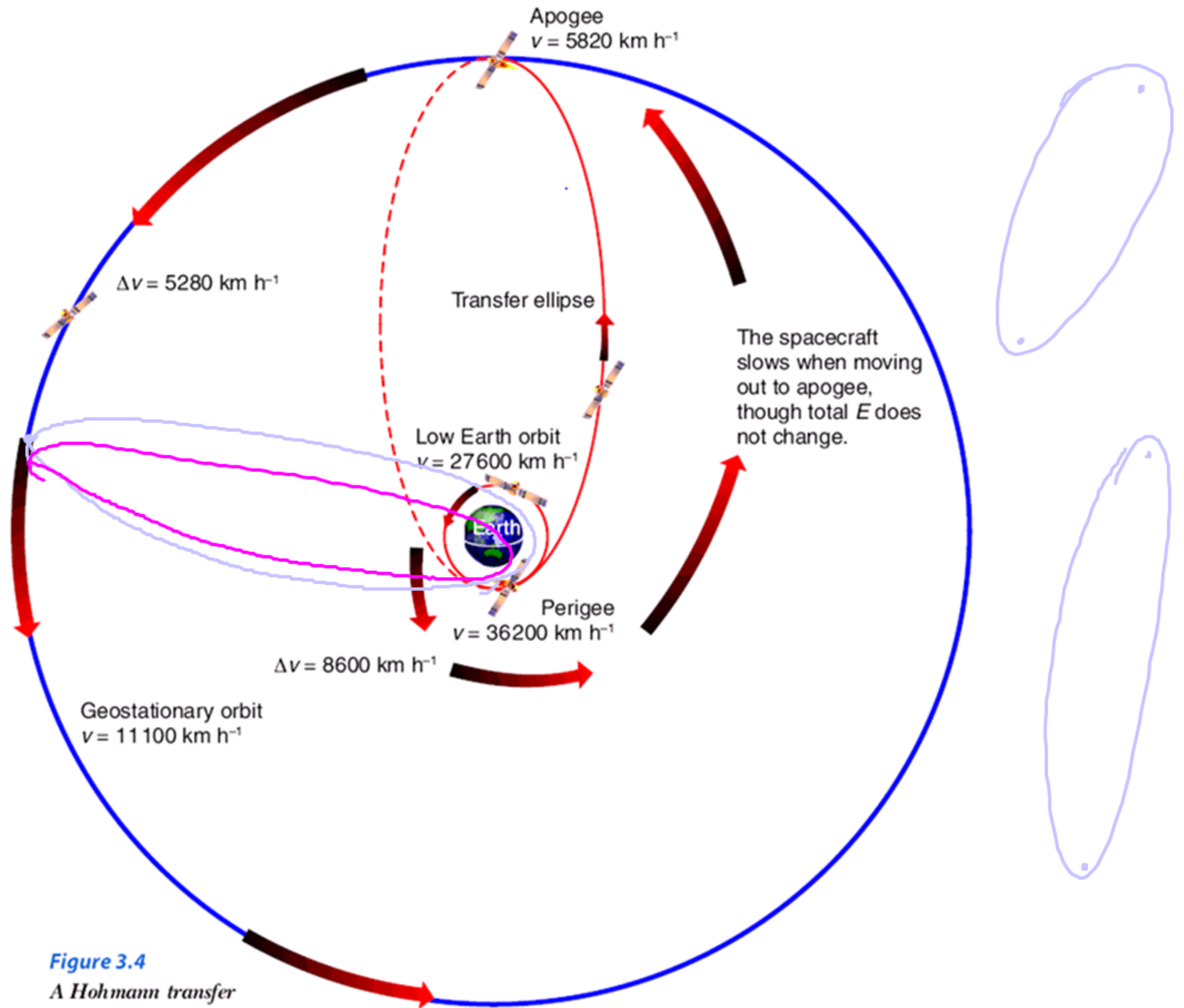
# SPACE

1<sup>st</sup> Quarter; Module 1

## PERIOD 17

### Universal Gravitational Force





**Figure 3.4**

*A Hohmann transfer orbit used to raise a satellite from a low Earth orbit of altitude 400 km up to a geostationary orbit of altitude 35 800 km*

# COMPARISON OF LOW EARTH AND GEOSTATIONARY ORBITS

$g = \frac{GM}{r^2}$	LEO	GO
velocity	$\sim 7000 \text{ m/s}$	$= 3070 \text{ m/s}$
period	1.5 - 2 h	$= 24.00 \text{ h}$
altitude	250 - 1000 km	36000 km
orbital radius	6700 - 7400 km	42'000 km
atmospheric drag	Significant	None
purpose	human, telescopes GPS	communication

# COMPARISON OF LOW EARTH AND GEOSTATIONARY ORBITS

	LEO	GO
What makes it special?	Under Van-Allen mag-field belts "PROTECTION FROM RADIATION & COSMIC PARTICLES FROM SPACE"	Above the same point on earth all the time

# ISSUES ASSOCIATED WITH SAFE RE-ENTRY AND LANDING

## 1. DE-ORBITING

1. RETROBURNING THE ROCKETS
2. GLIDING
3. RE-ENTRY

## 2. RE-ENTRY ANGLE

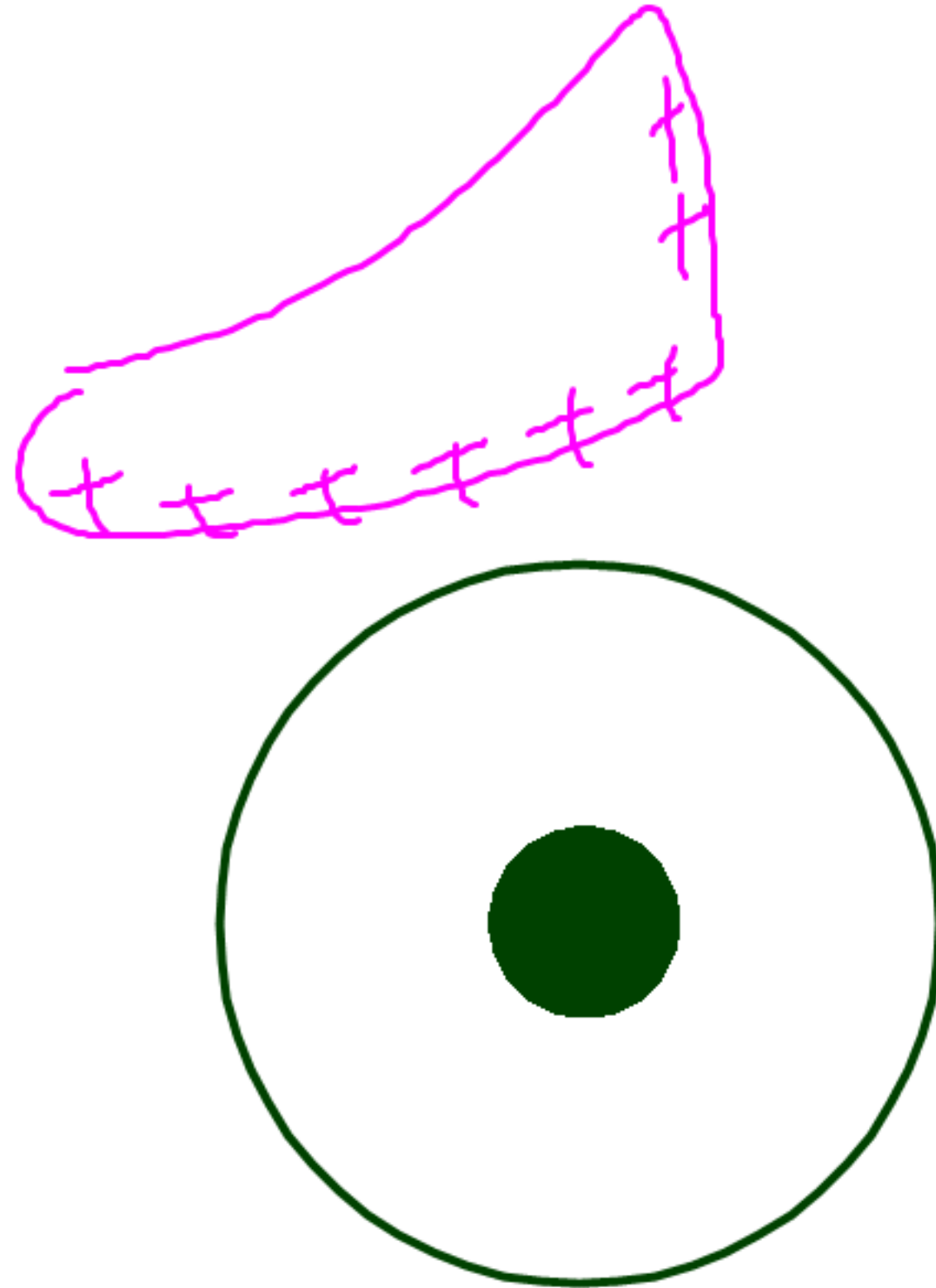
WHAT IF TOO DEEP?  
WHAT IF TOO SHALLOW?

### PROBLEMS

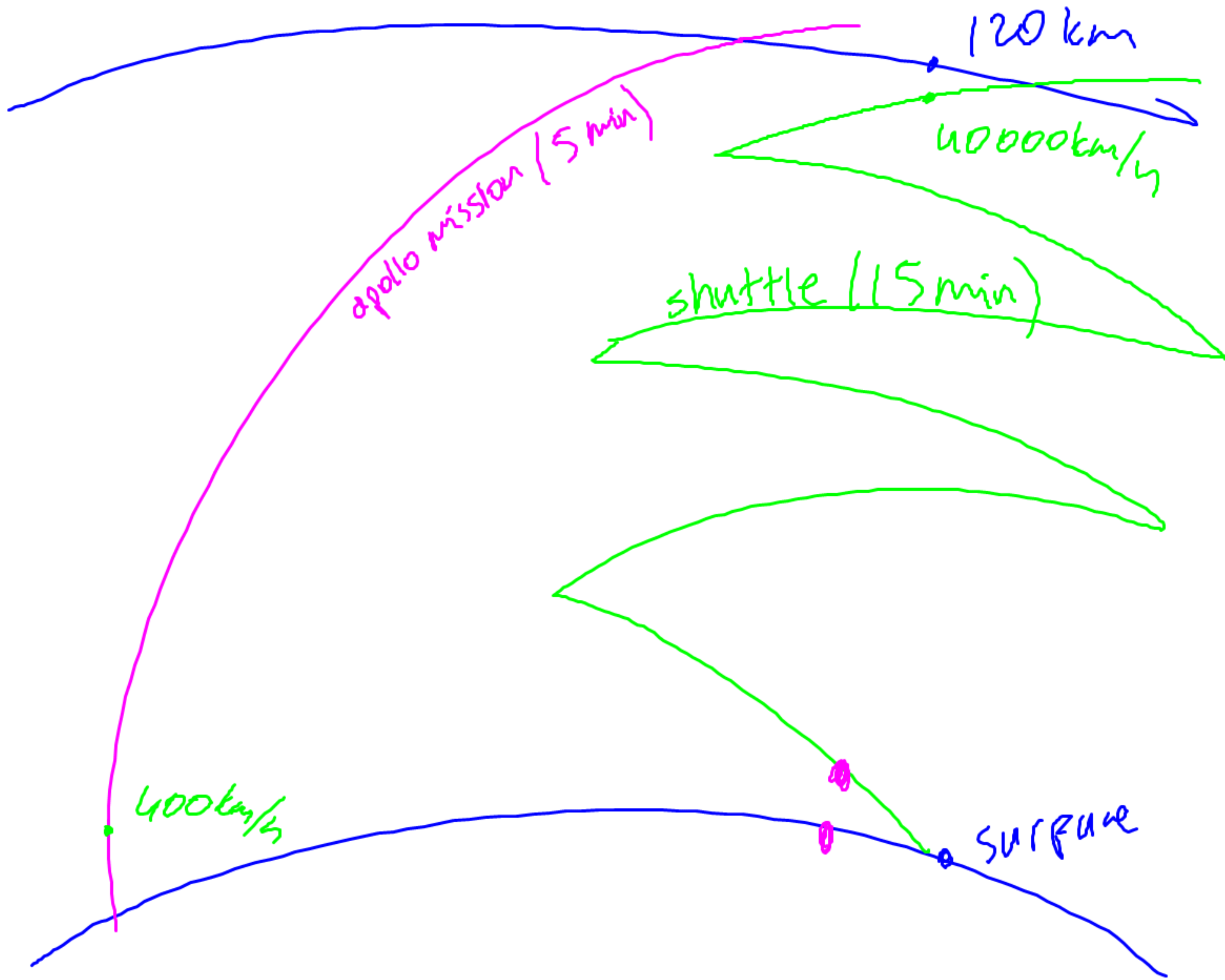
1. EXTREME HEAT
2. DECELERATING "g" FORCES
3. IONISATION BLACKOUT

## 3. LANDING

OLD US METHOD  
OLD RUSSIAN METHOD  
UPDATED RUSSIAN-CHINEESE METHOD  
SPACE SHUTTLE







## Space 2

**The Solar System is held together by gravity.**

*Students learn to:*

- describe a gravitational field in the region surrounding a massive object in terms of its effects on other masses in it
- define Newton's Law of Universal Gravitation

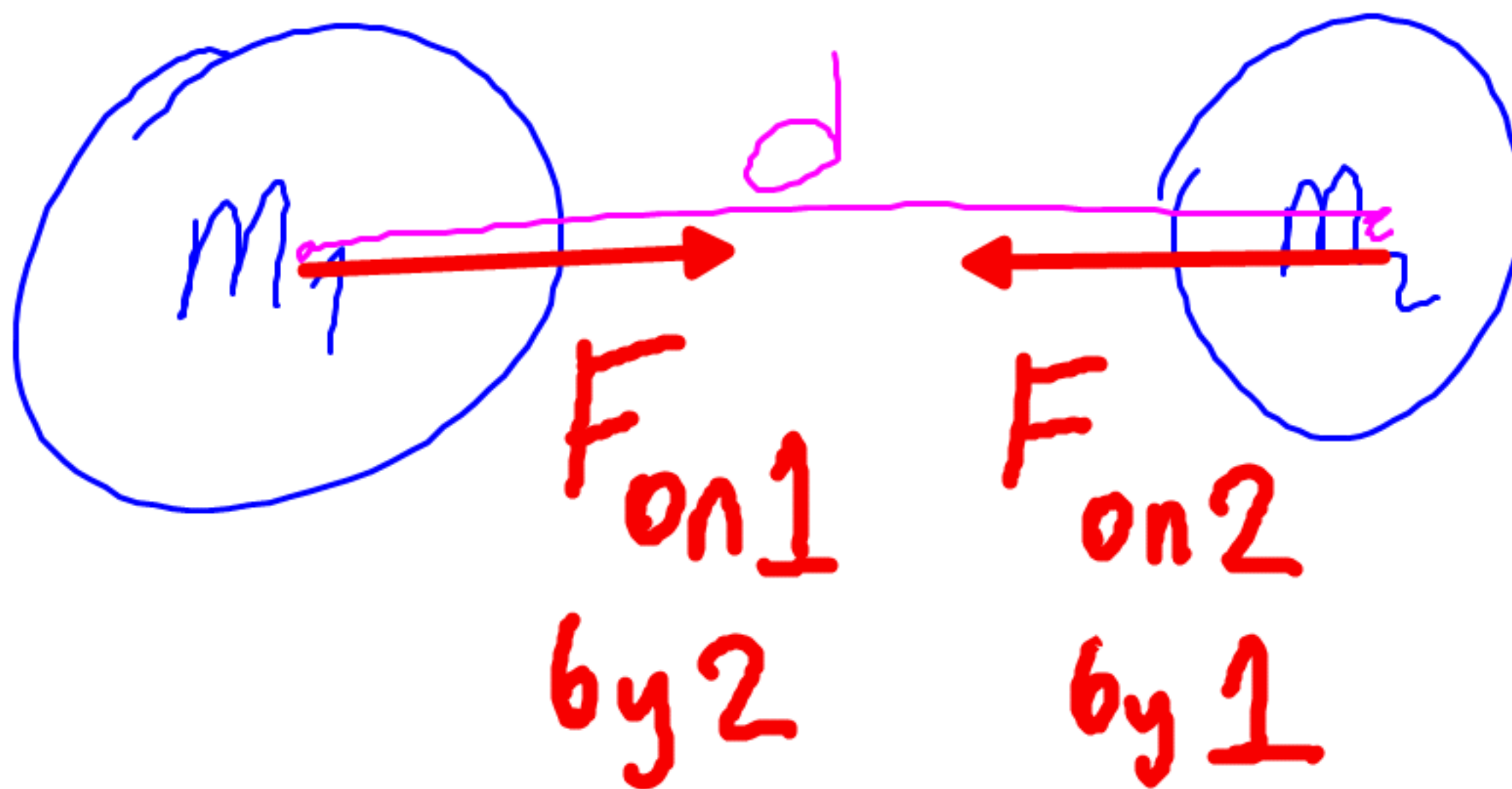
$$F = G \frac{m_1 m_2}{d^2}$$

- discuss the importance of Newton's Law of Universal Gravitation in understanding and calculating the motion of satellites
- identify that a slingshot effect can be provided by planets for space probes

*Students:*

- present information and use available evidence to discuss the factors affecting the strength of the gravitational force
- solve problems and analyse information using

$$F = G \frac{m_1 m_2}{d}$$



$$\vec{F}_{on1} = -\vec{F}_{on2}$$

(action  
reaction)



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

$F_g$ : gravitational attraction force b/w bodies

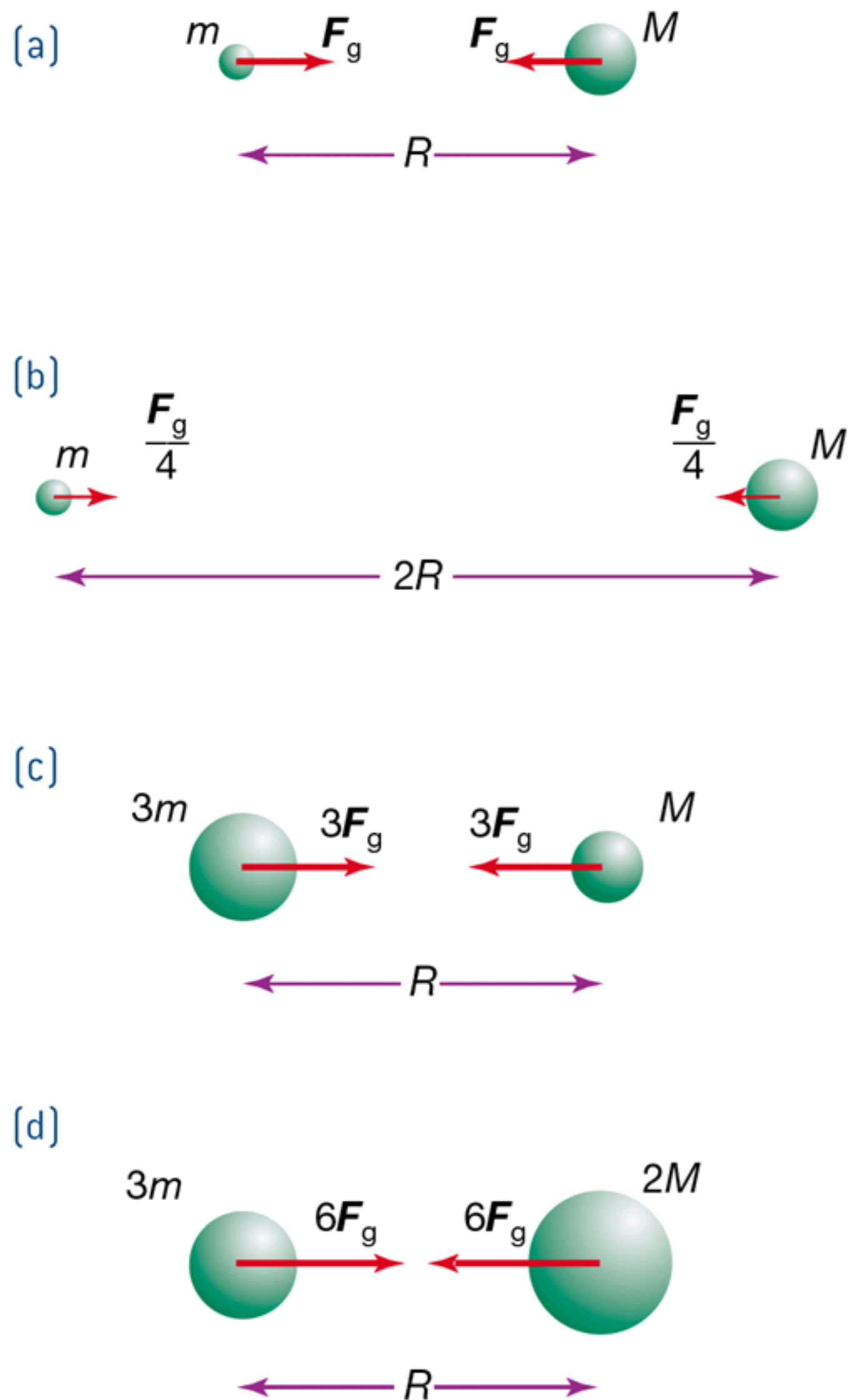
1912.

$m_1$ : mass of the body 1 (kg)

$m_2$ : " " " body 2 (kg)

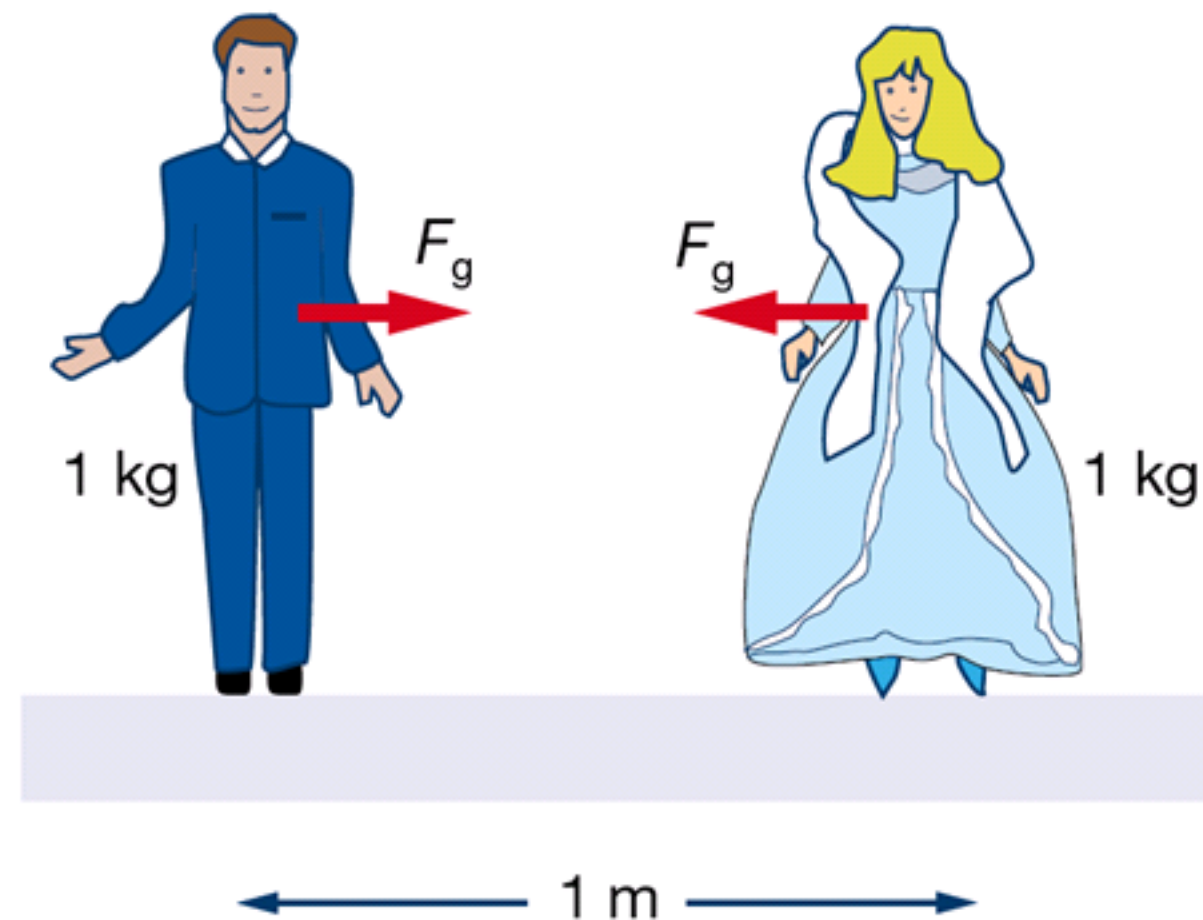
$d$ : the distance b/w centres (m)

$G$ : Un. gravitational constant  $(6.67 \times 10^{-11} \text{ N m}^2 / \text{kg}^2)$



**Figure 3.1** The gravitational force of attraction between two bodies depends on their separation and each of their masses.

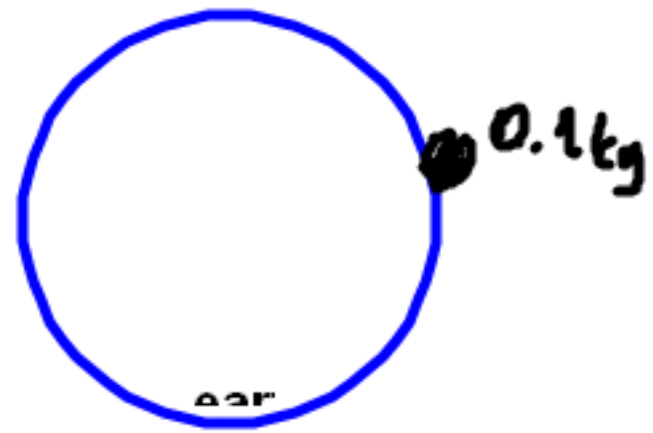
$$F_g = 6.67 \times 10^{-11} \text{ N} \quad F_g = 6.67 \times 10^{-11} \text{ N}$$



**Figure 3.2** The gravitational force of attraction between these two dolls is so weak that it does not cause them to be thrown together.

$$F_g = G \frac{mM}{(2R)^2}$$

Exercise 1 : Determine the gravitational force of attraction between



$$a) F = G \frac{m_{apple} \times M_{earth}}{d^2}$$

$$= 6.67 \times 10^{-11} \times \frac{0.1 \times 6 \times 10^{24}}{(6.4 \times 10^6)^2}$$

$$\approx 1 N \quad \left( \begin{array}{l} \text{weight of} \\ \text{the apple} \end{array} \right)$$

$$m \times g$$

$$0.1 \times 10 = 1 N$$

$$\frac{GM}{d^2} = 9.8 m/s^2 = g$$

$$F_{you} = 6.67 \times 10^{-11}$$

$m_{apple}$

$$\times \frac{80 kg \times 0.1 kg}{1^2}$$

$$= 5 \times 10^{-10} N$$



$$F_{\text{moon}} = \frac{6.67 \times 10^{-11} \times 7.4 \times 10^{22} \times 6 \times 10^{24}}{(3.84 \times 10^8)^2} = \underline{2 \times 10^{20} \text{ N}}$$

weight of the moon

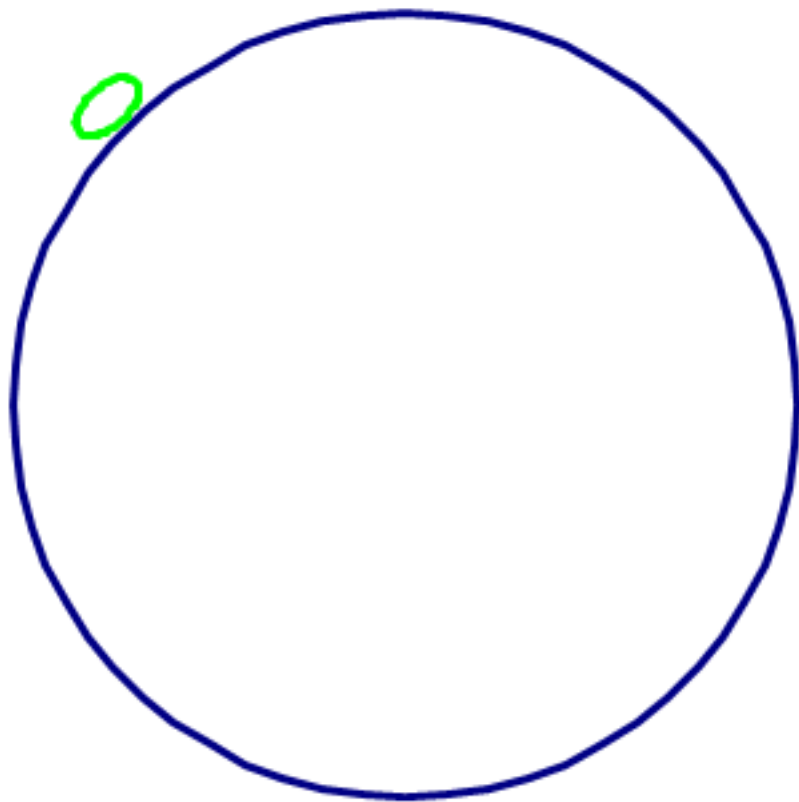


### Worked example 3.1A

A 10.0 kg watermelon falls a short distance to the ground. If the Earth has a radius of  $6.4 \times 10^6$  m (6400 km) and a mass of  $6.0 \times 10^{24}$  kg, calculate:

- a** the gravitational force that the Earth exerts on the watermelon
- b** the gravitational force that the watermelon exerts on the Earth
- c** the acceleration of the watermelon towards the Earth
- d** the acceleration of the Earth towards the watermelon.

$$a = \frac{F_{\text{net}}}{m} = 9.8$$



## Solution

- a** The gravitational force of attraction that the Earth exerts on the watermelon is:

$$\begin{aligned} F &= \frac{GMm}{R^2} \\ &= \frac{6.67 \times 10^{-11} \times 6.0 \times 10^{24} \times 10.0}{(6.4 \times 10^6)^2} \\ &= 98 \text{ N} \end{aligned}$$

- b** The watermelon also exerts a force of attraction of 98 N on the Earth. These forces are an action/reaction pair. Even though the forces acting on the Earth and the watermelon are equal in size, the effect of these forces on each body is very different.

- c** The acceleration of the watermelon is:

$$\begin{aligned} a &= \frac{\Sigma F}{m_{\text{melon}}} \\ &= \frac{98}{10} \\ &= 9.8 \text{ m s}^{-2} \text{ towards the centre of the Earth} \end{aligned}$$

This is, of course, the acceleration of all free-falling objects near the Earth's surface.

- d** The acceleration of the Earth is:

$$\begin{aligned} a &= \frac{\Sigma F}{m_{\text{Earth}}} \\ &= \frac{98}{6.0 \times 10^{24}} \\ &= 1.6 \times 10^{-23} \text{ m s}^{-2} \text{ towards the centre of the watermelon} \end{aligned}$$

The motion of the Earth is hardly affected by the gravitational force of the watermelon.

## 4.1

### ***Determining gravitational forces in the Sun–Earth–Moon system***

Given the following data, determine the magnitude of the gravitational attraction between:

- (a) the Earth and the Moon
- (b) the Earth and the Sun.

$$\text{Mass of the Earth} = 5.97 \times 10^{24} \text{ kg}$$

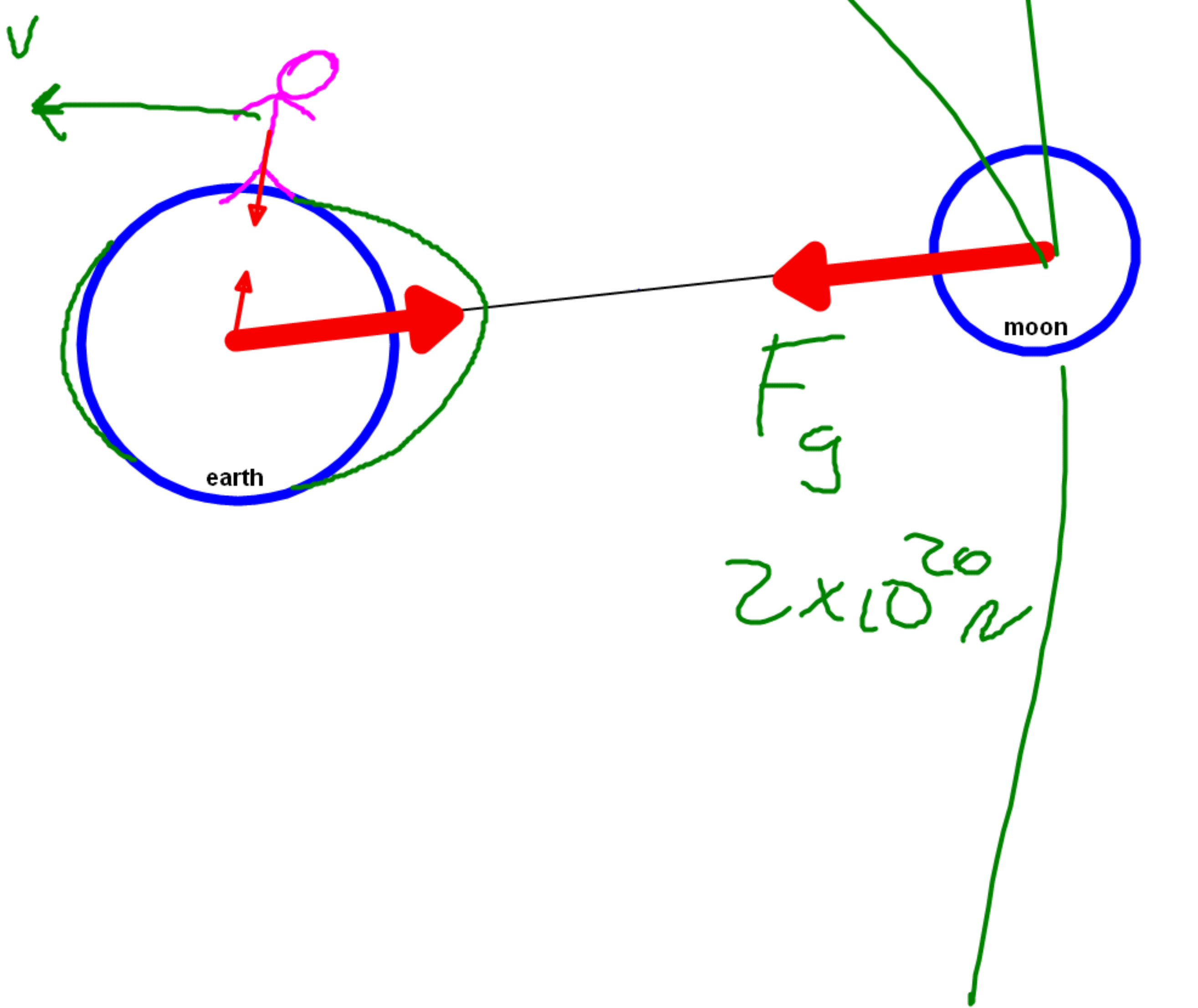
$$\text{Mass of the Moon} = 7.35 \times 10^{22} \text{ kg}$$

$$\text{Mass of the Sun} = 1.99 \times 10^{30} \text{ kg}$$

$$\text{Earth–Moon distance} = 3.84 \times 10^8 \text{ m on average}$$

$$\text{Earth–Sun distance} = 1.50 \times 10^{11} \text{ m on average (one astronomical unit, AU)}$$

WHAT IS THE DIFFERENCE BETWEEN YOU AND THE MOON (IN TERMS OF MOTION)?

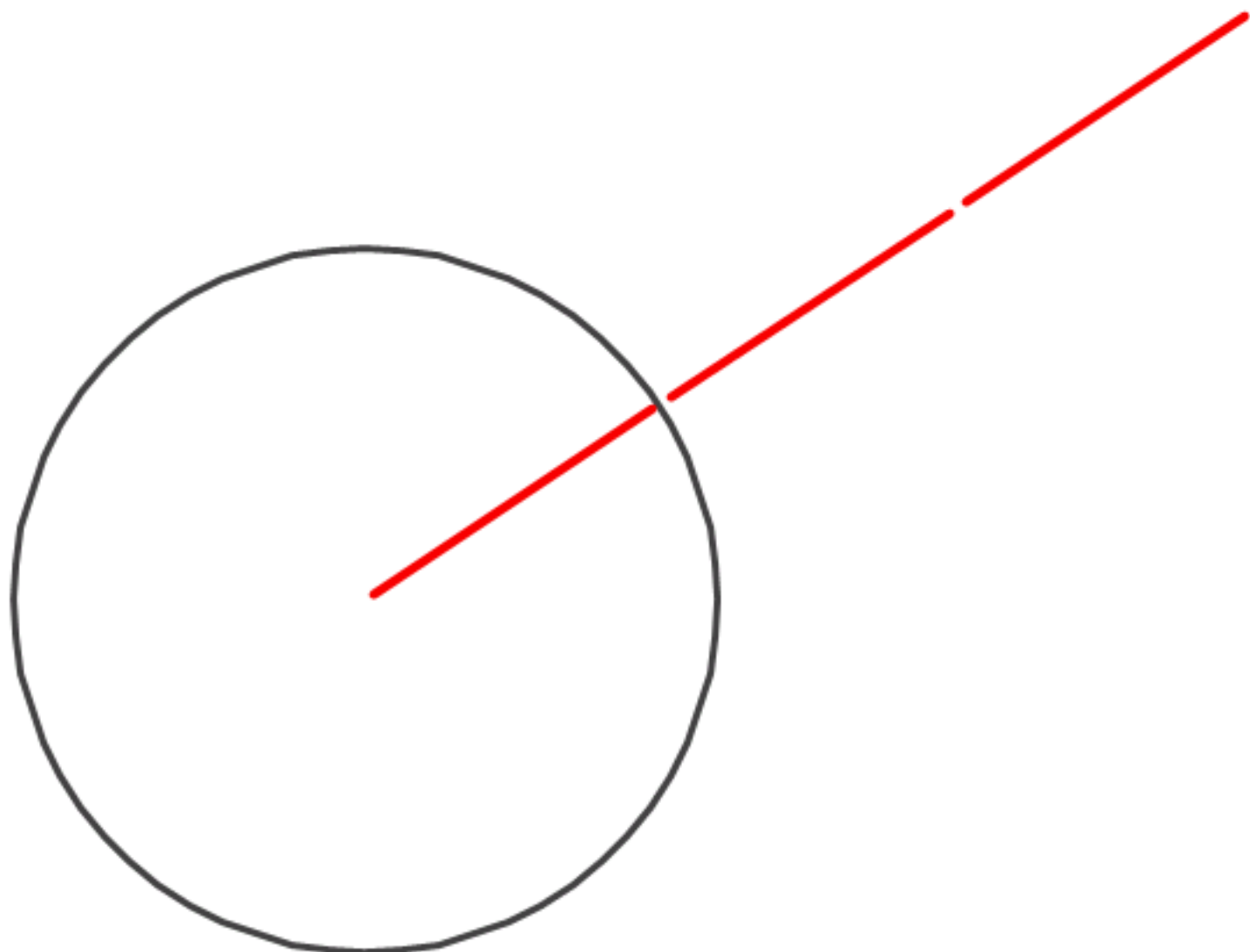




### Worked example 3.1B

The gravitational force that acts on a 1200 kg space probe on the surface of Mars is  $4.43 \times 10^3$  N. The radius of Mars is 3400 km. Without using the mass of Mars, determine the gravitational force that acts on the space probe when it is:

- a** 3400 km above the surface of Mars
- b** 6800 km above the surface of Mars.



## Solution

- a** There is an inverse square relationship between gravitational force and the distance between the centres of the objects:

$$\text{i.e. } F \propto \frac{1}{R^2}$$

When it is sitting on the surface of Mars, the probe is 3400 km from the centre of the planet and the gravitational force acting on it is  $4.43 \times 10^3$  N. When the probe is at an altitude of 3400 km, it is 6800 km from the centre of Mars. This is double the distance from the centre compared to when it was on the surface. If the distance between the masses has doubled, then the size of the forces acting must be one-quarter of the original value:

$$\begin{aligned}\text{i.e. } F &= \frac{4.43 \times 10^3}{2^2} \\ &= \frac{4.43 \times 10^3}{4} \\ &= 1.11 \times 10^3 \text{ N}\end{aligned}$$

The inverse square nature of the relationship between force and distance can also be used to determine the force:

$$\begin{aligned}\frac{F_2}{F_1} &= \frac{R_1^2}{R_2^2} \\ \therefore \frac{F_2}{4.43 \times 10^3} &= \frac{3400^2}{6800^2}\end{aligned}$$

$$\therefore F_2 = 1.11 \times 10^3 \text{ N}$$

If this ratio approach is used, it is not necessary to use standard SI units, but the units used for each of the quantities must be the same.

- b** At 6800 km above the surface of Mars, the probe is 10 200 km from the centre. This is three times its separation from the centre when it was on the surface, and so the gravitational force will be one-ninth of its original strength:

$$\begin{aligned}\text{i.e. } F &= \frac{4.43 \times 10^3}{3^2} \\ &= \frac{4.43 \times 10^3}{9} \\ &= 492 \text{ N}\end{aligned}$$

The ratio of the forces and distances can again be used to find the size of this force:

$$\begin{aligned}\frac{F_2}{F_1} &= \frac{R_1^2}{R_2^2} \\ \therefore \frac{F_2}{4.43 \times 10^3} &= \frac{3400^2}{10\,200^2} \\ \therefore F_2 &= 492 \text{ N}\end{aligned}$$



## HOMEWORK (DUE TOMORROW)

For these questions, assume that  $G = 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$ , and that distances are measured between the centres of the bodies.

**1** For this question, assume that:

mass of Earth =  $6.0 \times 10^{24} \text{ kg}$

radius of Earth =  $6.4 \times 10^6 \text{ m}$

mass of the Moon =  $7.3 \times 10^{22} \text{ kg}$

mean radius of Moon's orbit =  $3.8 \times 10^8 \text{ m}$

Calculate the gravitational force of attraction that exists between the following objects.

- a** A 100 g apple and a 200 g orange that are 50 cm apart
- b** A pair of 1000 kg boulders that are 10.0 m apart
- c** The Earth and a satellite of mass 20 000 kg in orbit at an altitude of 600 km
- d** The Moon and the Earth
- e** The Earth and a 60 kg student standing on its surface
- f** A proton of mass  $1.67 \times 10^{-27} \text{ kg}$  and an electron of mass  $9.11 \times 10^{-31} \text{ kg}$  separated by  $5.30 \times 10^{-11} \text{ m}$  in a hydrogen atom

**5** A comet of mass 1000 kg is plummeting towards Jupiter. Jupiter has a mass of  $1.90 \times 10^{27} \text{ kg}$  and a planetary radius of  $7.15 \times 10^7 \text{ m}$ . If the comet is about to crash into Jupiter, calculate the following:

- a** the magnitude of the gravitational force that Jupiter exerts on the comet
- b** the magnitude of the gravitational force that the comet exerts on Jupiter
- c** the acceleration of the comet towards Jupiter
- d** the acceleration of Jupiter towards the comet.

**6** An astronaut travels away from Earth to a region in space where the gravitational force due to Earth is only 1.0% of that at Earth's surface. What distance, in Earth radii, is the astronaut from the centre of the Earth?

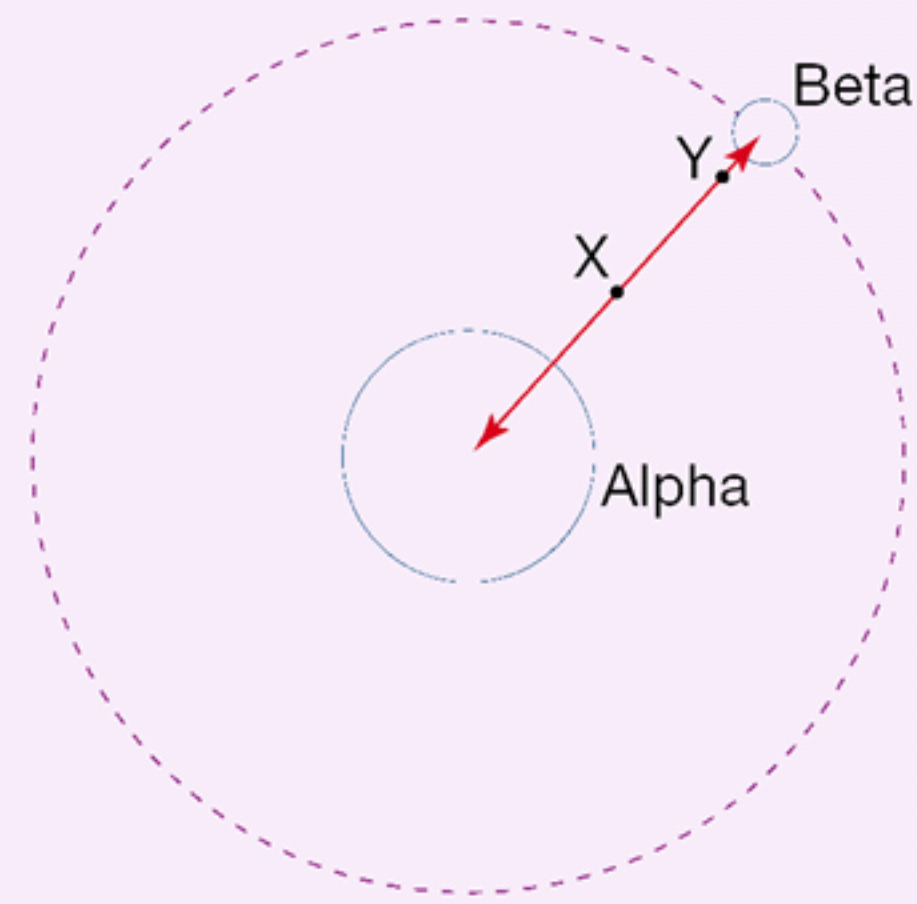
The following information applies to questions 7 and 8. The planet Alpha, whose mass is  $M$ , has one moon Beta of mass  $0.01M$ . The mean distance between the centres of Alpha and Beta is  $R$ .





hydrogen atom

- 2 Newton's law of universal gravitation defines the symbol  $G$  as a 'universal constant'.
- a Explain the meaning of this term and its significance.
- b Identify another universal constant.
- 3 An astronaut standing on the surface of the Moon experiences a gravitational force of attraction of 160 N. He then moves away from the surface of the Moon to an altitude where the gravitational force is 40 N.
- a How far from the centre of the Moon is this new location in terms of the radius of the Moon?
- b The astronaut now travels to another location at a height of three Moon radii above the surface. Calculate the gravitational force at this altitude.
- 4 Mars has two natural satellites. Phobos has a mean orbital radius of  $9.4 \times 10^6$  m, while the other moon, Deimos, is located at a mean distance of  $2.35 \times 10^7$  m from the centre of Mars. Data: mass of Mars =  $6.42 \times 10^{23}$  kg; mass of Phobos =  $1.08 \times 10^{16}$  kg; mass of Deimos =  $1.8 \times 10^{15}$  kg.
- Calculate the value of the ratio:
- $$\frac{\text{gravitational force exerted by Mars on Phobos}}{\text{gravitational force exerted by Mars on Deimos}}$$



- 7 a If an asteroid is at point X, exactly halfway between the centres of Alpha and Beta, calculate the value of the ratio:
- $$\frac{\text{force exerted on asteroid by Alpha}}{\text{force exerted on asteroid by Beta}}$$
- b At what distance, expressed in terms of  $R$ , from the planet Alpha, along a straight line joining the centres of Alpha and Beta, will the ratio expressed in part a be equal to 8100?
- 8 Point Y represents the distance from planet Alpha where the magnitude of the net gravitational force is zero. What is this distance in terms of  $R$ ?



# **HOMEWORK**

- ✦ Homework is an integral part of your "Learning Curve", take it seriously!
- ✦ Target minimum 1 hour of Physics everyday
- ✦ Divide your physics home study in three segments;
  - ✓ Revision (past)
  - ✓ Homework (present)
  - ✓ Tomorrow (future)
- ✦ Homework is due next period, unless otherwise stated
- ✦ If you cannot do all, at least do a few from each piece

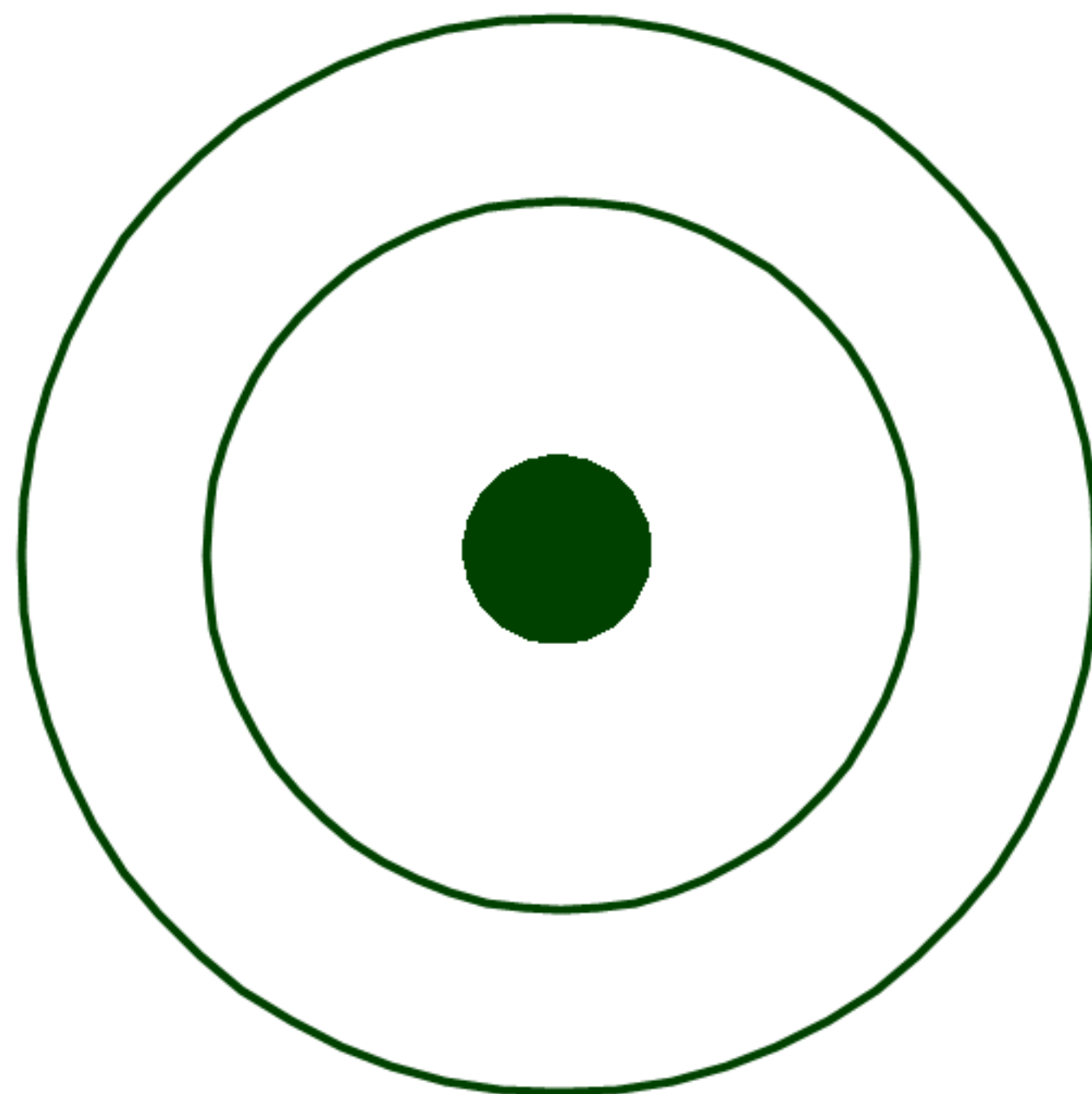
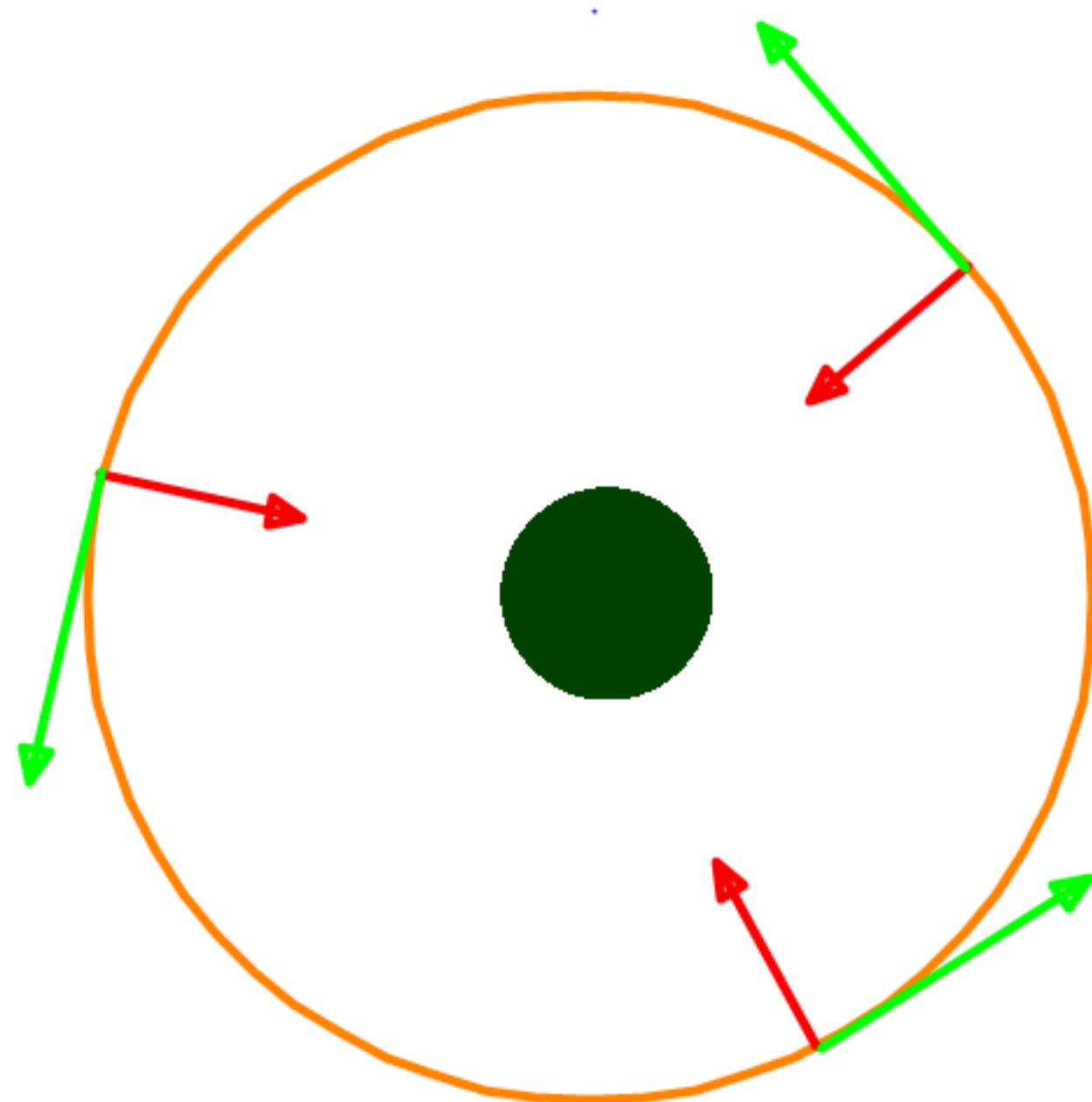
*Apart from **reading the relevant pages from the textbook and solving the rest of the questions in this booklet**  
your homework is:*

- ✓ **8 questions in this booklet**
- ✓ Experiment 5 Report
- ✓ Relevant pages in Multiple Choice Dot Points Book (DPB)
- ✓ New 8 page booklet (pages 16-23)
- ✓ Chapter 3 all questions

**NEXT PERIOD > SLINGSHOT EFFECT**

# COMPARISON OF COMMON CIRCULAR MOTIONS

MOTION	$F_c$ PROVIDED BY ...
Whirling rock on a string	The string
Electron orbiting atomic nucleus	Electron–nucleus electrical attraction
Car cornering	Friction between tyres and road
Moon revolving around Earth	Moon–Earth gravitational attraction
Satellite revolving around Earth	Satellite–Earth gravitational attraction
Lady bug on a rotating disc	Friction b/w her hairy feet and the disc
Principal rotating the girl in the movie "Mathilda"	Tension in their arms
Playground swing	Tension in the rope
Vortex	Reaction force from the walls
Earth revolving around the Sun	Earth-Sun gravitational attraction



## Steps in solving PM questions.

Step 1 > Read the question.

Step 2 > Understand the question.

Step 3 > Make sure you understand "What is given/provided" and "What is asked".

Step 4 > Draw a diagram.

Step 5 > Select your interval (A to B). Mark A and B on your diagram.

Step 6 > Draw the data table and fill in the details as much as you can. Mark unknowns.

Step 7 > Select the appropriate formula and solve it for unknowns.