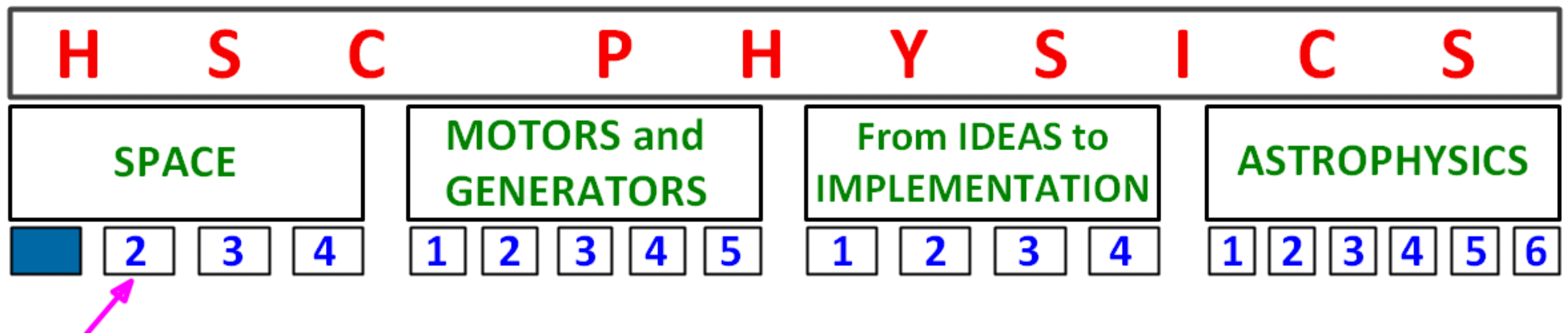


SPACE

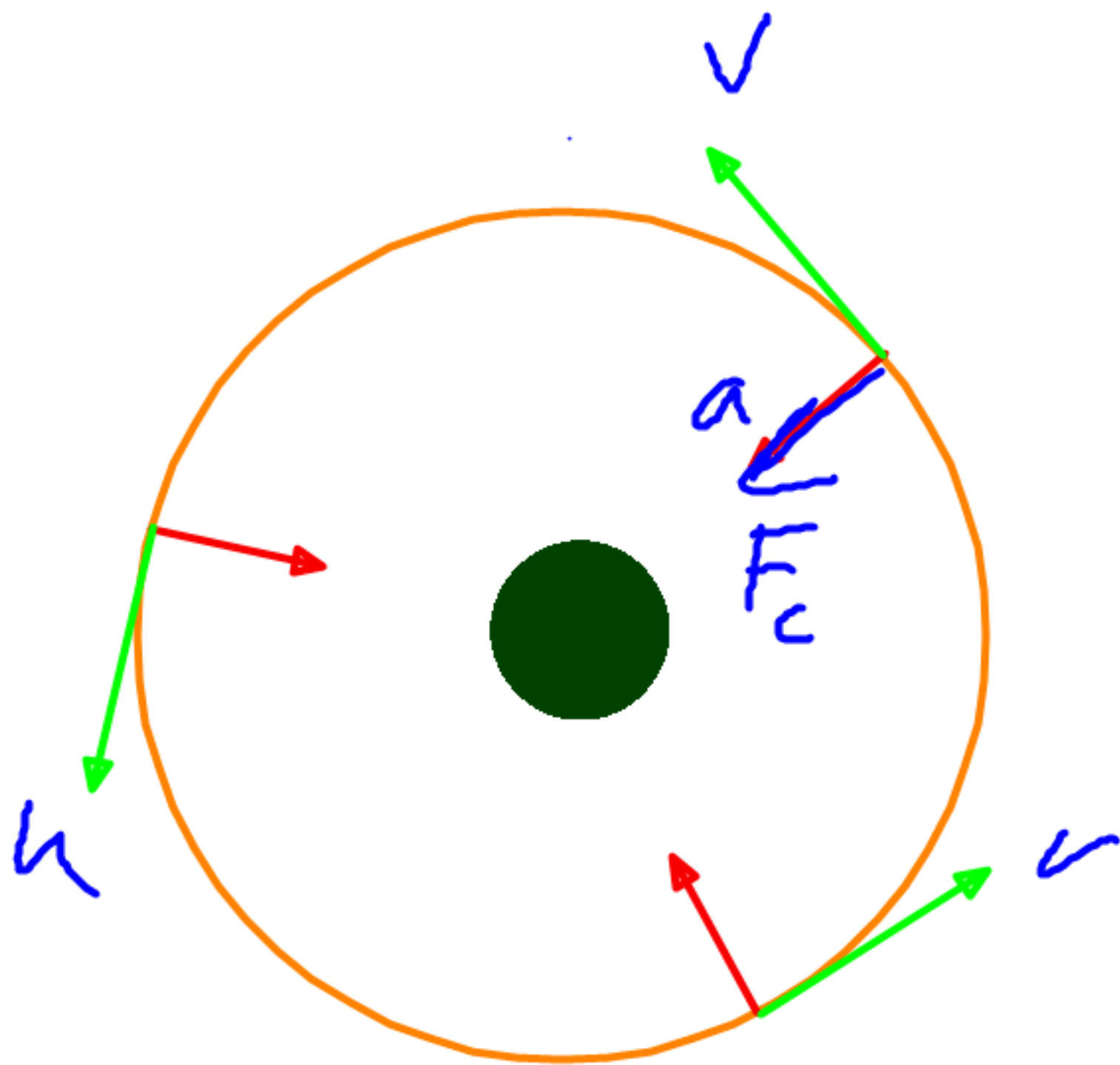
1st Quarter; Module 1

PERIOD 13

Circular Motion - Kepler's Laws



CIRCULAR MOTION REVISITED



$$F_c = \frac{mv^2}{r}$$

$$v = \frac{2\pi r}{T}$$

SOURCES OF CENTRIPETAL FORCE

MOTION	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
$F_c = F_{\text{net}}$	

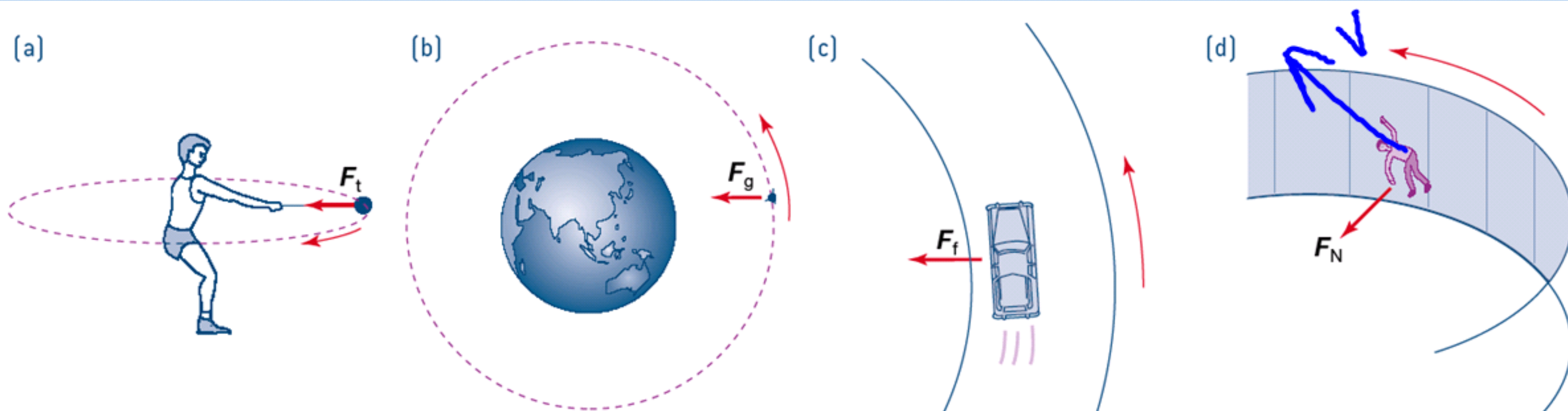
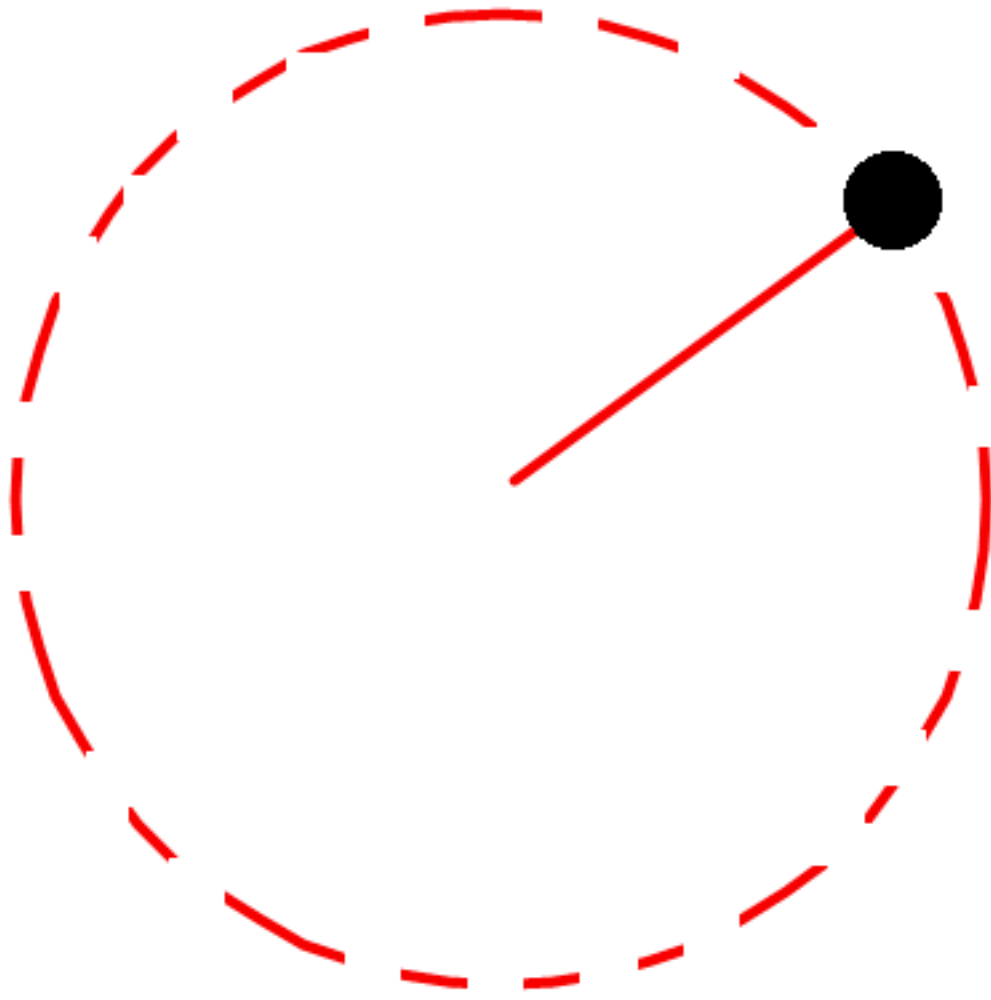
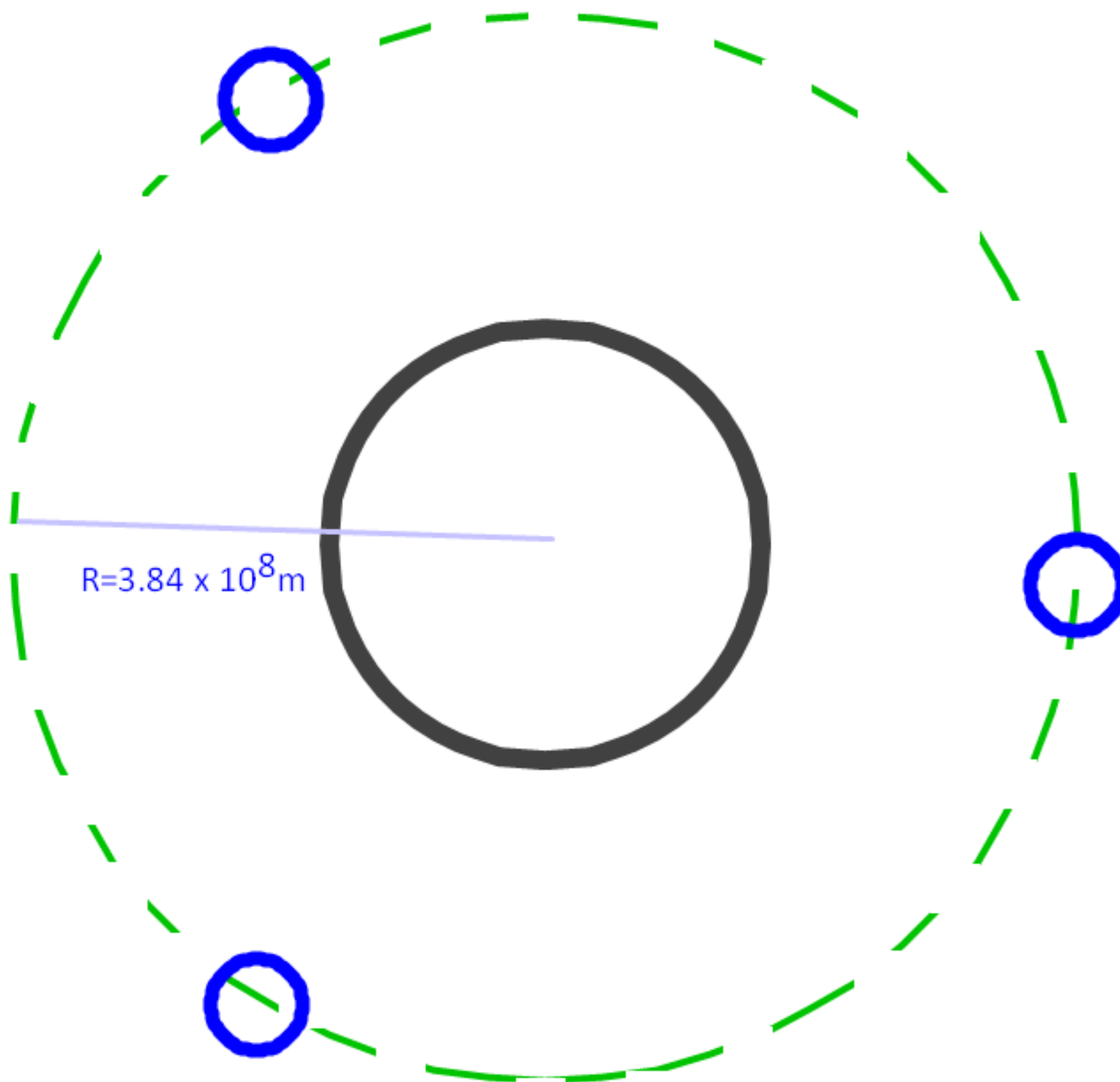


Figure 2.34 The centripetal force that produces a centripetal acceleration and hence a circular motion is provided by different real forces. (a) In a hammer throw or for any other object rotated while attached to an arm or wire, it is the tension in the arm or wire that provides the centripetal force. (b) For planets and satellites, the gravitational attraction to the central body provides the centripetal force. (c) For a car on a roundabout, it is the friction between the tyres and the road. (d) For a person in the Gravitron it is the normal force from the wall. Although the person feels that they are being pinned to the wall, the wall is in fact applying a force to their body.

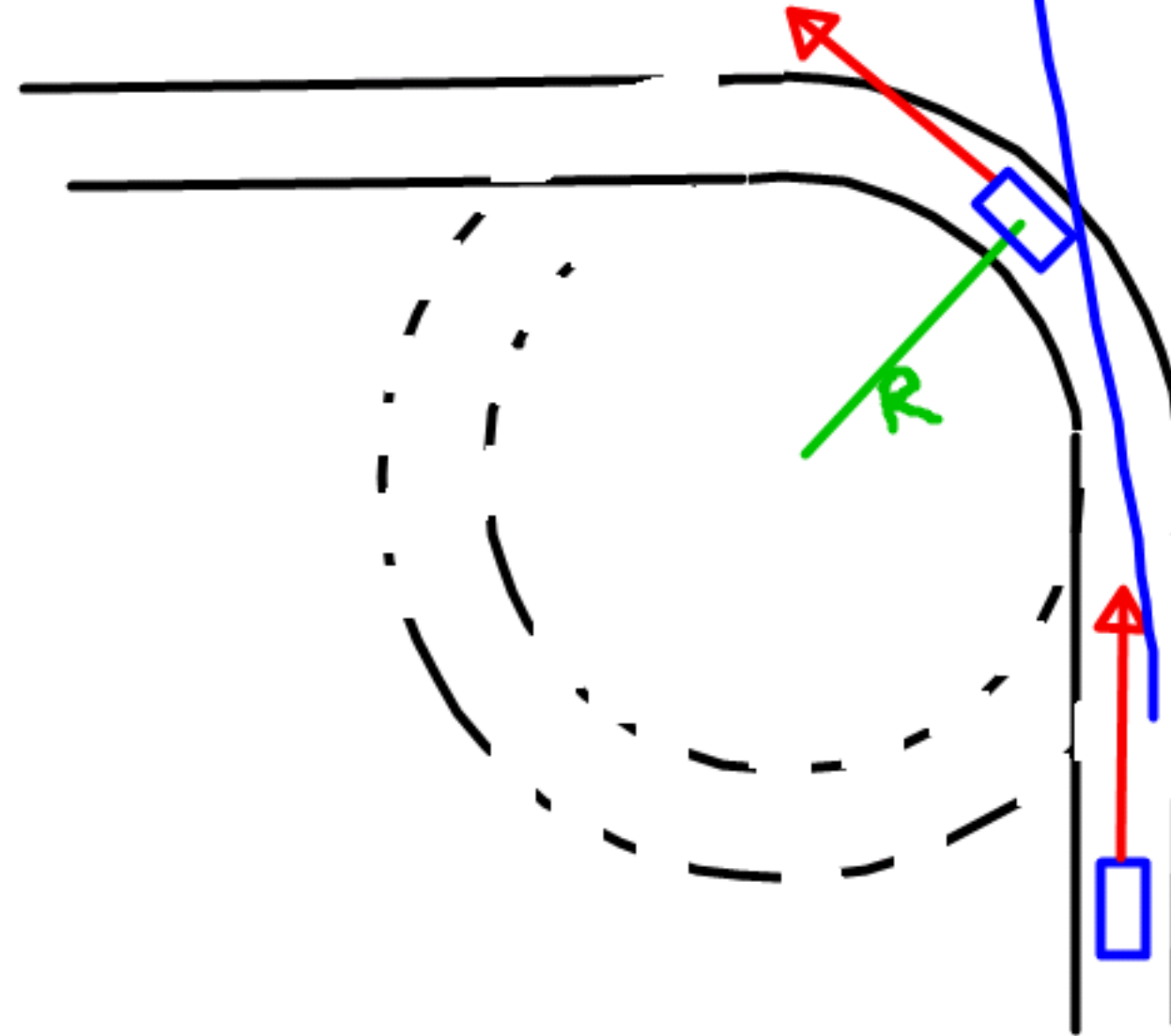
Exercise 2: A rock of mass 250 g is attached to the end of a 1.5 m long string and whirled in a horizontal circle at 15 m/s. Show the velocity, acceleration and net force on the rock and then calculate the centripetal force and acceleration of the rock.



Exercise 3: Find the orbital velocity of the moon and the force on the moon if it completes one orbit in 28 days and has an orbital radius of 384 000 km.



Exercise 4: A car of mass 1450 kg is driven around a bend of radius 70 m. Determine the frictional force required between the tyres and the road in order to allow the car to travel at 70 km/h?1.



$$F_c = F_f = \frac{mV^2}{R}$$

$$= \frac{1450 \times 20^2}{70\text{m}}$$

$$= 8000\text{N}$$

$$F_{f_{\text{max}}} = 9000\text{N}$$

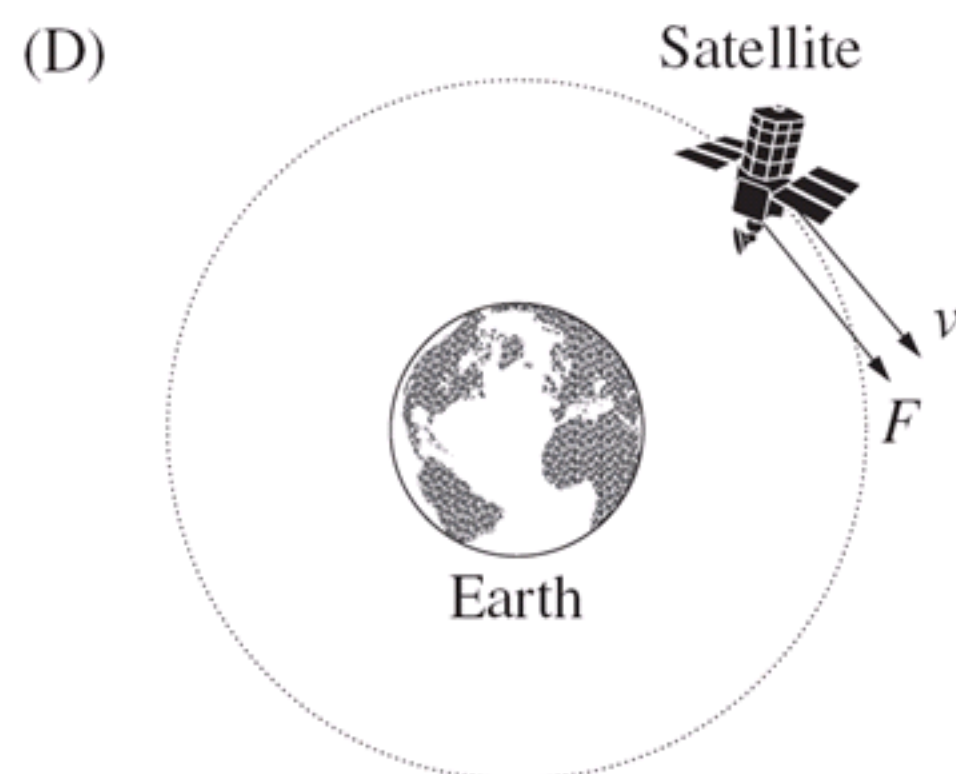
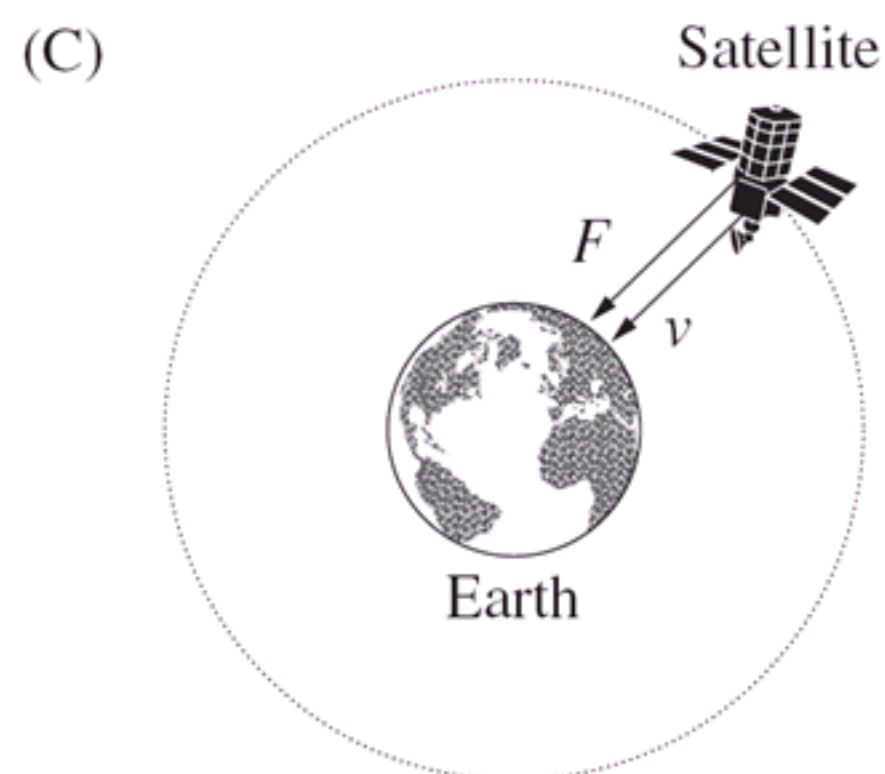
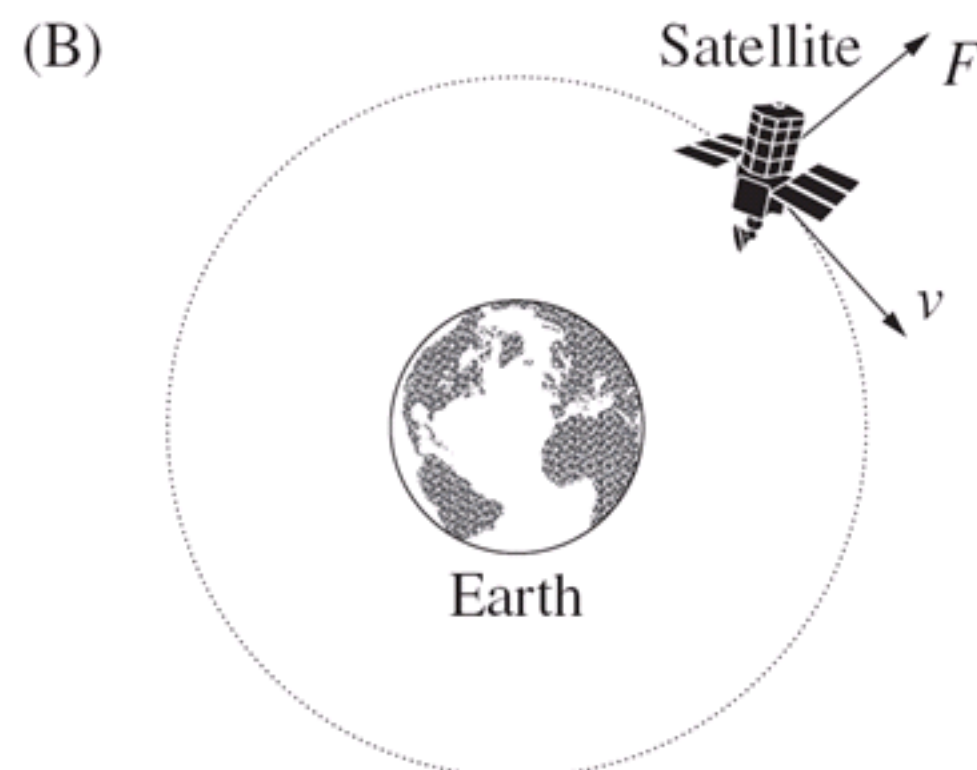
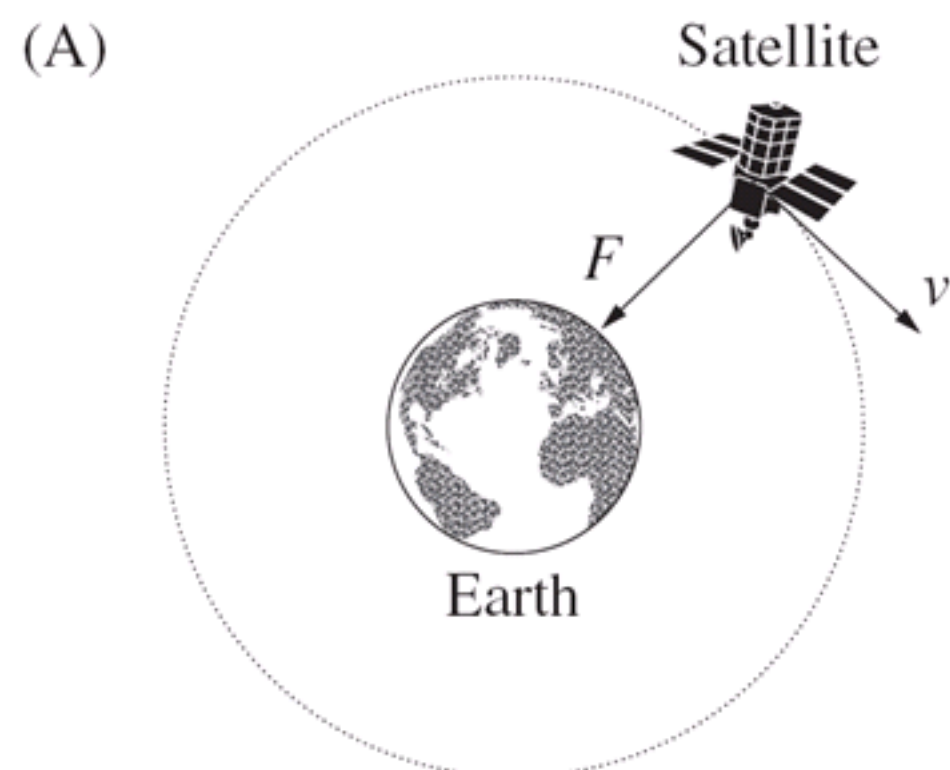
- 2 A satellite moves in uniform circular motion around Earth.

The following table shows the symbols used in the diagrams below.
These diagrams are NOT drawn to scale.

Key

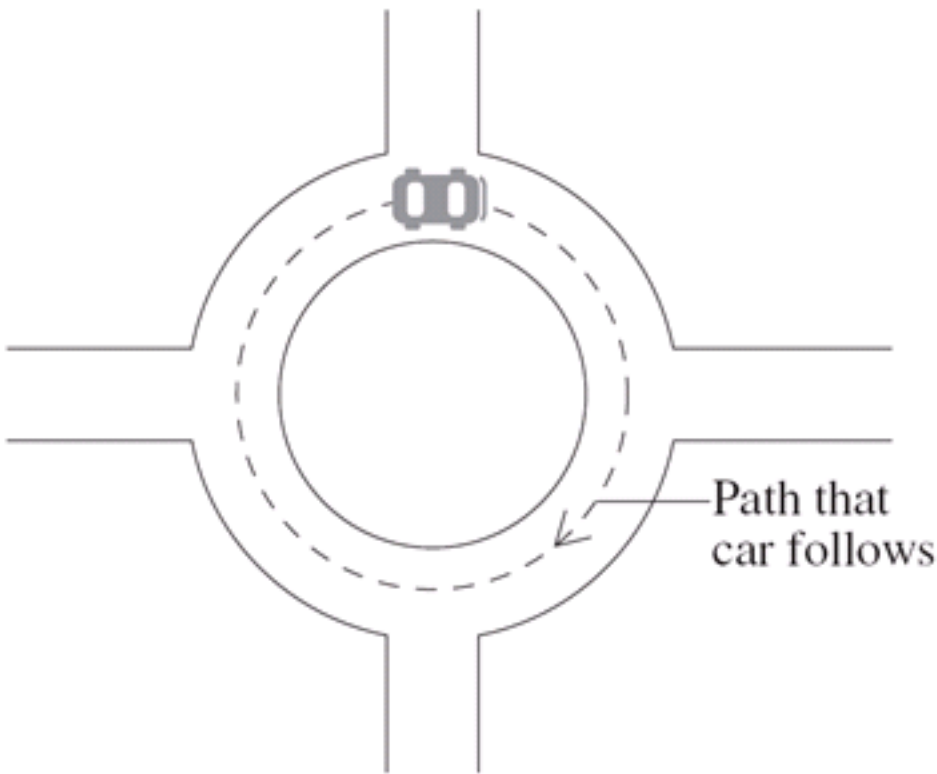
F	net force on satellite
v	velocity of satellite

Which diagram shows the direction of F and v at the position indicated?



Question 18 (4 marks)

A car with a mass of 800 kg travels at a constant speed of 7.5 m s^{-1} on a roundabout so that it follows a circular path with a radius of 16 m.



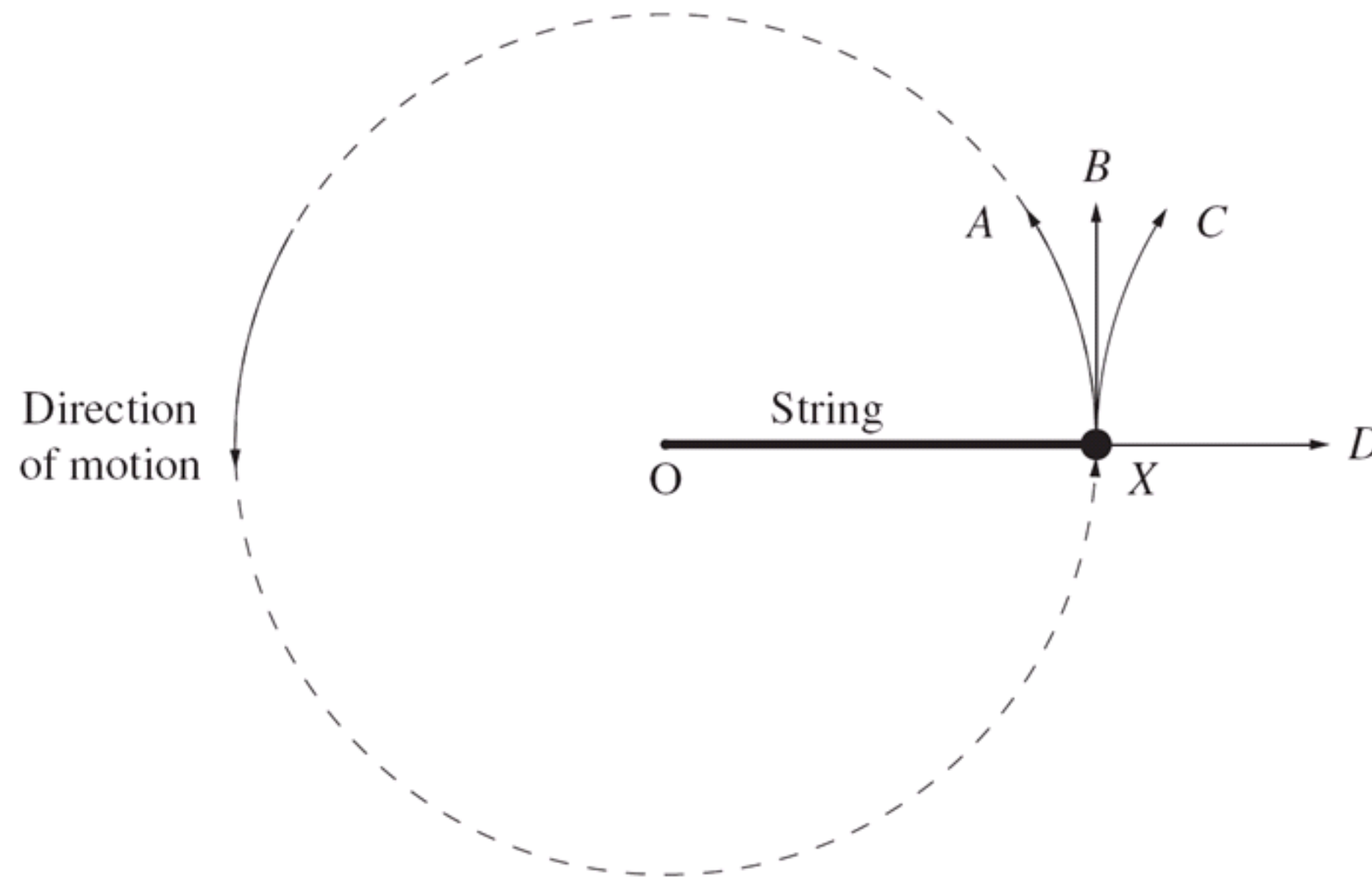
A person observing this situation makes the following statement.

‘There is no net force acting on the car because the speed is constant and the friction between the tyres and the road balances the centripetal force acting on the car.’

Assess this statement. Support your answer with an analysis of the horizontal forces acting on the car, using the numerical data provided above.

4

- 2 A mass attached to a length of string is moving in a circular path around a central point, O, on a flat, horizontal, frictionless table. This is depicted in the diagram below. The string breaks as the mass passes point X.



Which line best depicts the subsequent path of the mass?

- (A) Line A
- (B) Line B
- (C) Line C
- (D) Line D

KEPLER'S LAWS

Kepler's three laws of planetary motion are:

1. The orbit of every planet is an ellipse with the sun at a focus.
2. A line joining a planet and the sun sweeps out equal areas during equal intervals of time.
3. The square of the orbital period of a planet is directly proportional to the cube of the semi-major axis of its orbit.

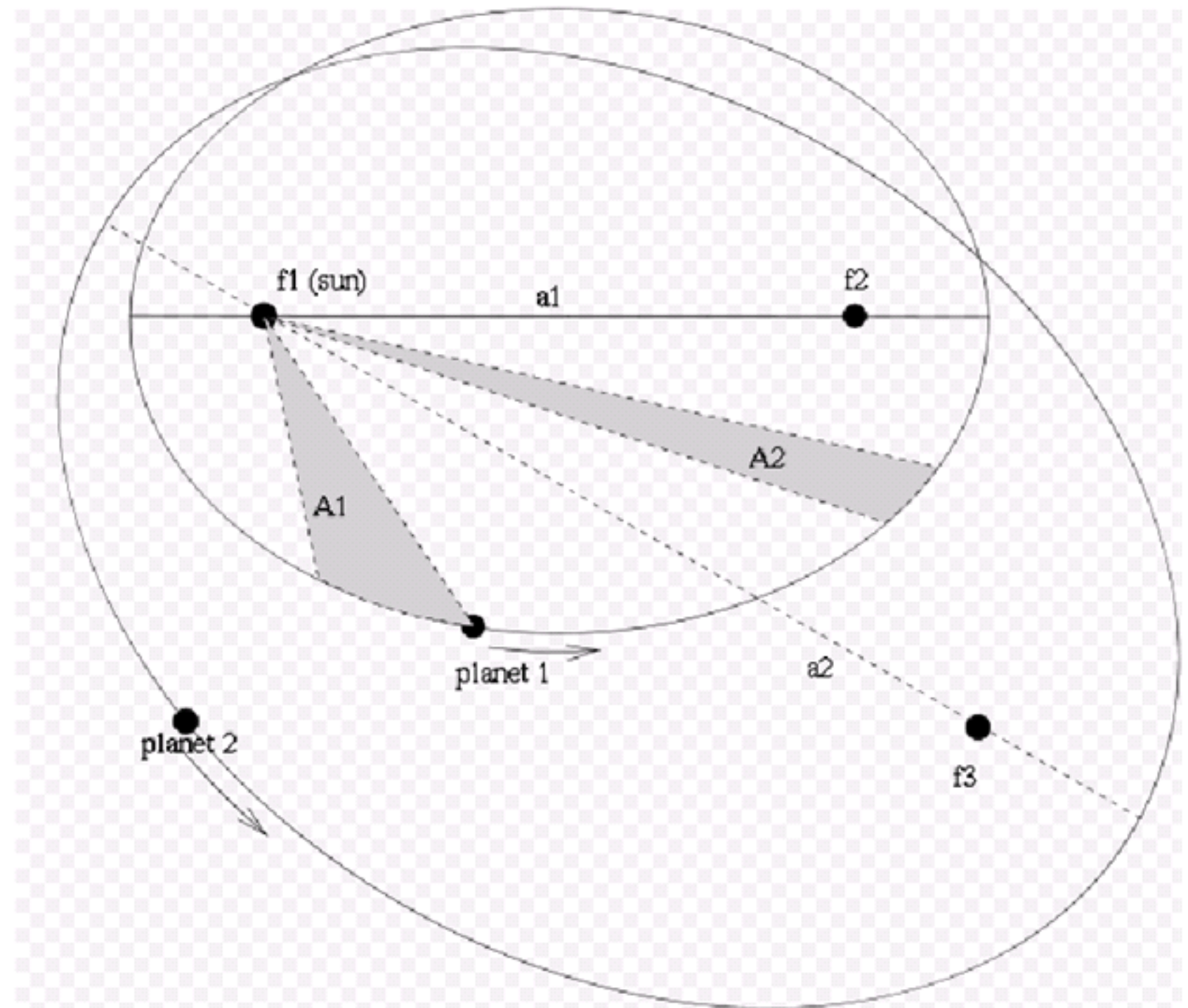
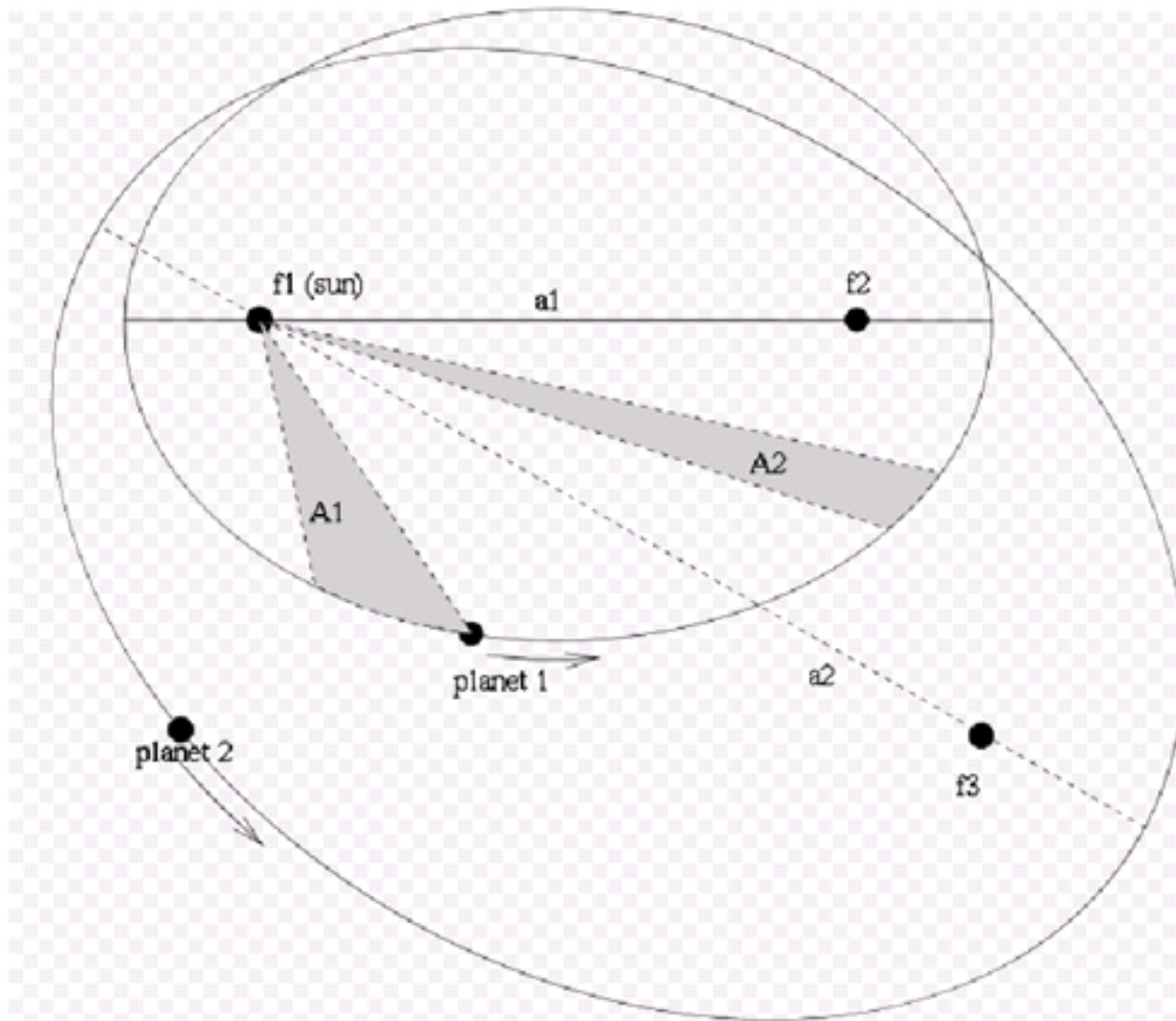


Figure 1: Illustration of Kepler's three laws with two planetary orbits. (1) The orbits are ellipses, with focal points f_1 and f_2 for the first planet f_1 and f_3 for the second planet. The sun is placed in focal point f_1 . (2) The two shaded sectors A_1 and A_2 have the same surface area and the time for planet 1 to cover segment A_1 is equal to the time to cover segment A_2 . (3) The total orbit times for planet 1 and planet 2 have

KEPLER'S THIRD LAW



$$\frac{T^2}{R^3} = \frac{4\pi^2}{GM}$$

$$\frac{R^3}{T^2} = \frac{GM}{4\pi^2}$$

T : period of the satellite (s)

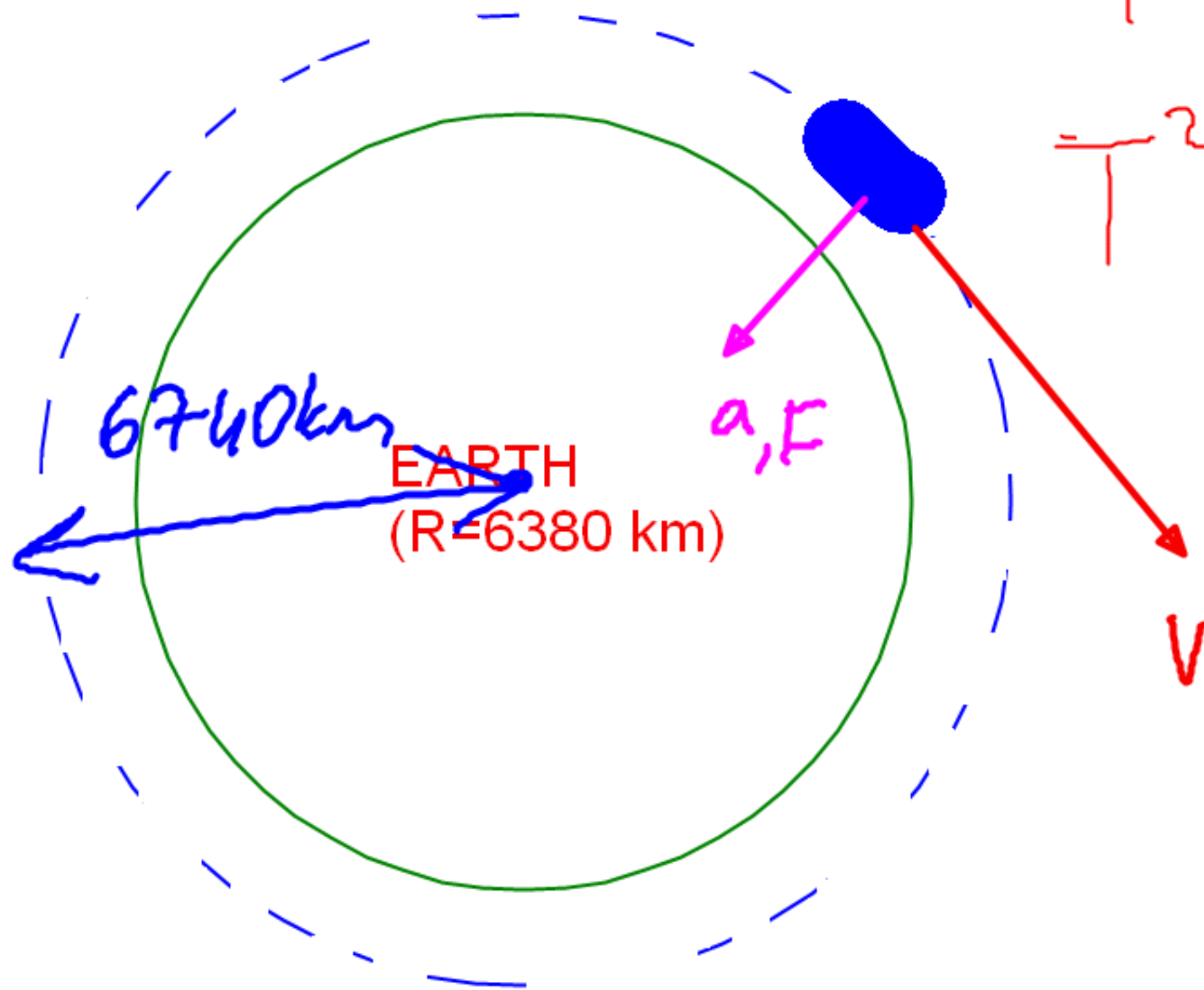
R : radius of orbit of sat. (m)

M : mass of the central body.

G : univ. gravitational constant.

EXERCISE 1: Find the period (then velocity) of ISS which is orbiting around the Earth at an altitude of 360 km. Show the net force acting on it first.

$$R = 6380 + 360 = 6740 \text{ km} \\ = 6.74 \times 10^3 \text{ km} = 6.74 \times 10^6 \text{ m}$$



$$\frac{R^3}{T^2} = \frac{GM}{4\pi^2}$$

$$T^2 GM = 4\pi^2 R^3$$

$$T = \sqrt{\frac{4\pi^2 R^3}{GM}}$$

$$= 5500 \text{ s} \approx 1.5 \text{ h}$$

EXERCISE 2: Find the orbital radius and velocity of the Earth around the sun if it completes one turn in 365.25 days

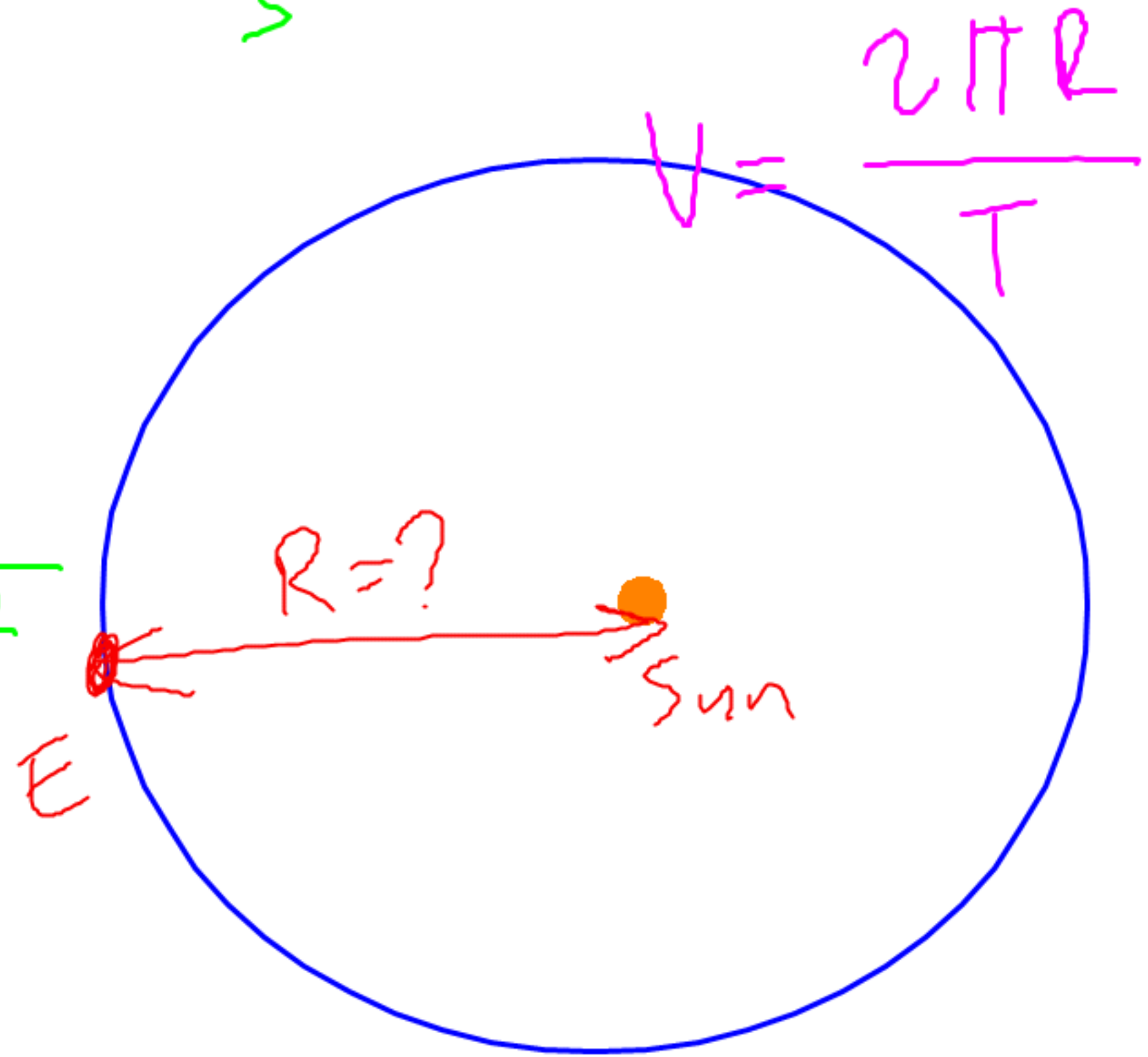
$$\frac{R^3}{T^2} = \frac{GM}{4\pi^2}$$

$$T = 365.25 \times 24 \times 60 \times 60 \quad M_{\text{Sun}} = 2 \times 10^{30} \text{ kg}$$

$$R^3 = \frac{GM T^2}{4\pi^2}$$

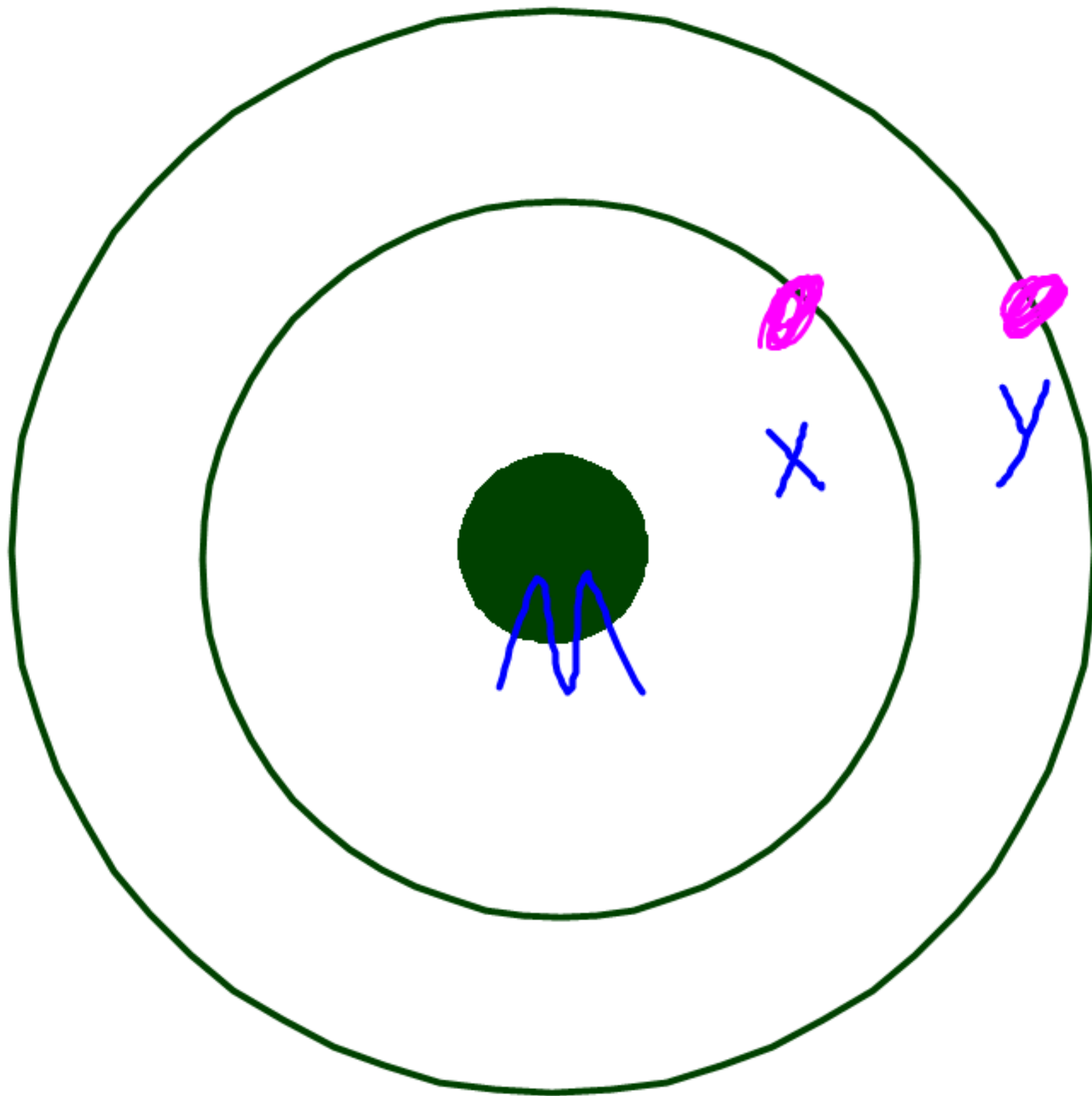
$$R = \sqrt[3]{\frac{6.67 \times 10^{-11} \times 2 \times 10^{30} \times T^2}{4\pi^2}}$$

$$R \approx 1.5 \times 10^{11} \text{ m}$$



KEPLER'S THIRD LAW TO COMPARE SATELLITES

$$\frac{R_x^3}{T_x^2} = \frac{GM}{4\pi^2} = \frac{R_y^3}{T_y^2}$$

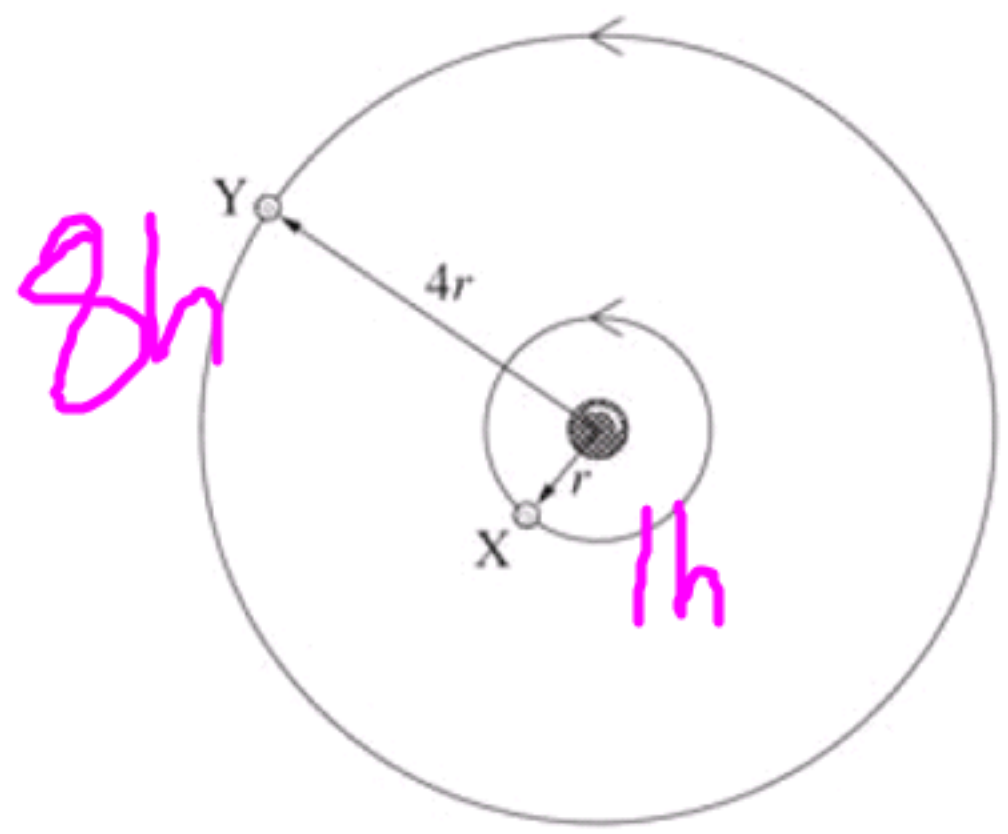


$$\frac{R_x^3}{T_x^2} = \frac{R_y^3}{T_y^2}$$

2003 HSC QUESTION

4 Two planets, X and Y, travel around a star in the same direction, in circular orbits.

Planet X completes one revolution about the star in time T . The radii of the orbits are in the ratio 1 : 4.



How many revolutions does planet Y make about the star in the same time T ?

- (A) $\frac{1}{8}$ revolution
- (B) $\frac{1}{2}$ revolution
- (C) 2 revolutions
- (D) 8 revolutions

$$\sqrt{T_y^2} = \sqrt{64T^2}$$

$$T_y = 8T$$

Handwritten pink notes above the equations:

X	r	T
Y	4r	?

Blue equations:

$$\frac{r^3}{T^2} = \frac{(4r)^3}{T_y^2}$$
$$\frac{\cancel{r^3}}{T^2} = \frac{64\cancel{r^3}}{T_y^2}$$

2005 HSC QUESTION

Question 16 (5 marks)

From nearest to furthest, the four satellite moons of Jupiter first observed by Galileo in the year 1610 are called Io, Europa, Ganymede and Callisto. For the first three moons, the orbital period T of each is exactly twice the period of the one orbiting immediately inside it. That is,

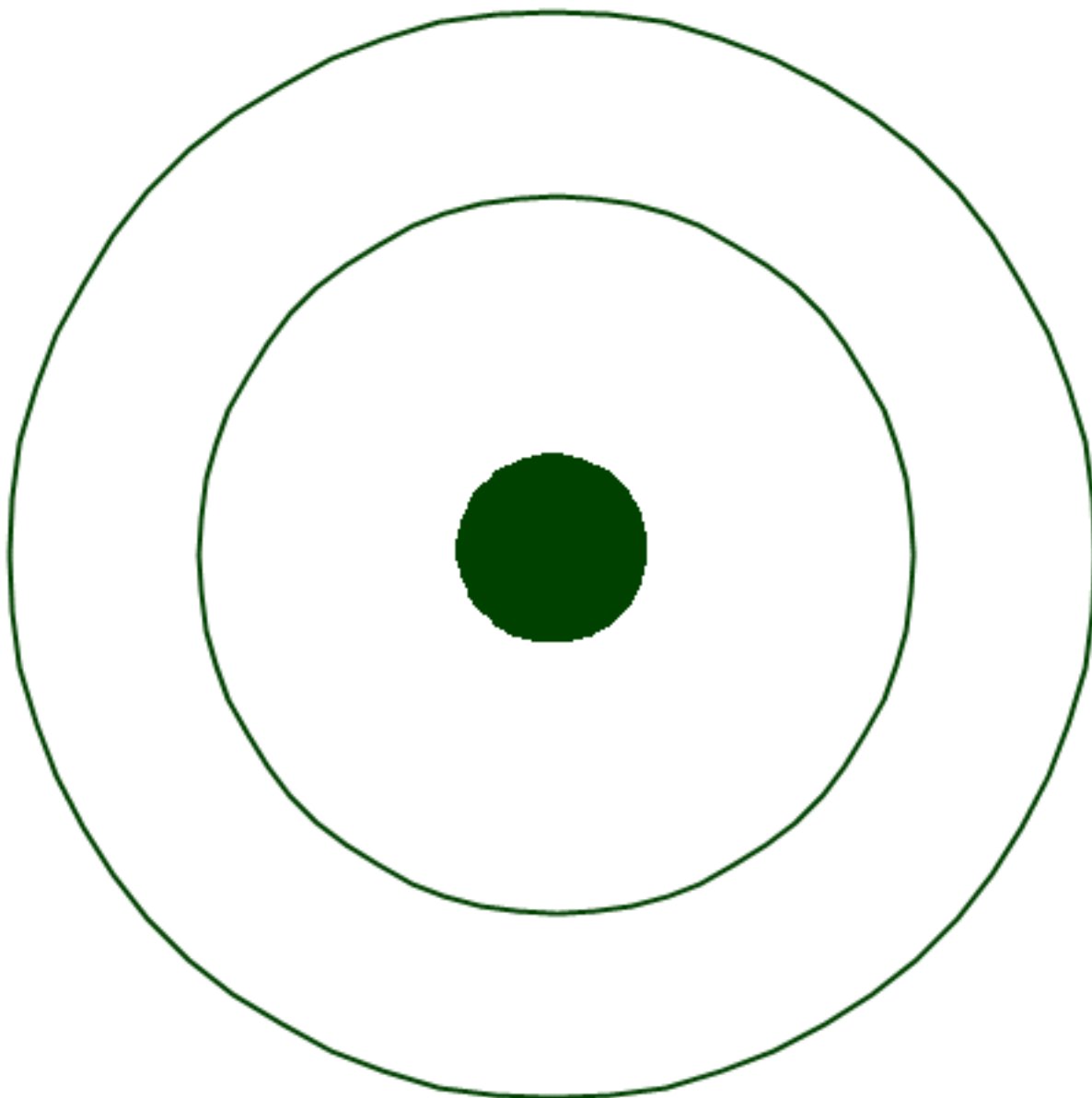
$$T_{\text{Europa}} = 2 \times T_{\text{Io}}$$

$$T_{\text{Ganymede}} = 2 \times T_{\text{Europa}}$$

The mass of Jupiter is 1.90×10^{27} kg, and the orbital radius of Io is 421 600 km.

- (a) Use Kepler's Law of Periods to calculate Ganymede's orbital radius.

2



Question 16 (5 marks)

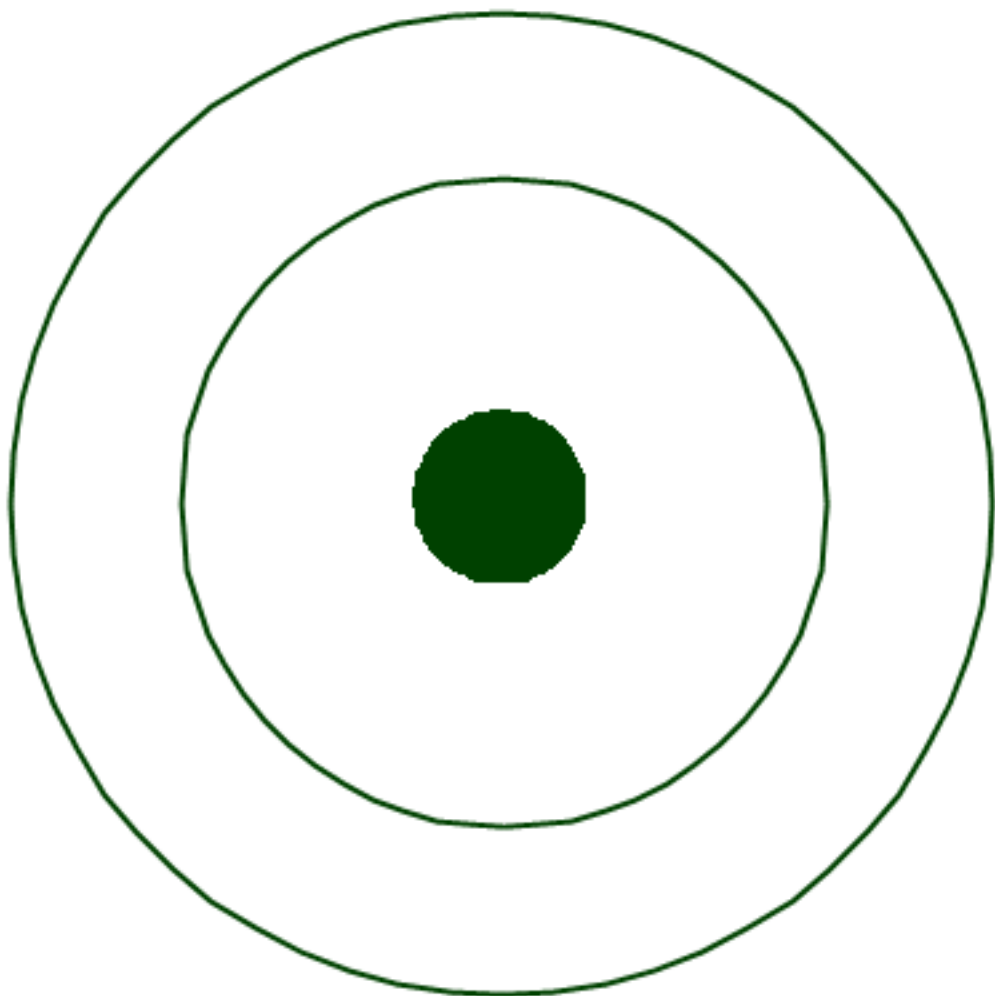
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$$\mathbf{T}_{\text{Europa}} = 2 \times \mathbf{T}_{\text{Io}}$$

$$\mathbf{T}_{\text{Ganymede}} = 2 \times \mathbf{T}_{\text{Europa}}$$

The mass of Jupiter is 1.90×10^{27} kg, and the orbital radius of Io is 421 600 km.

(b) Calculate Ganymede's orbital speed.



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:*

1. Space 2 Past Year Questions
2. Chapter 3 all questions
3. Experiment 3 of the Practical Booklet

Also

Circular Motion Worksheet

New Booklet (8 page)

Chapter 2 All Questions

PM Practice Booklet

All Questions in Period 7 & 8 Booklets

Experiment 4 Report

NEXT PERIOD > SAFE RE-ENTRY