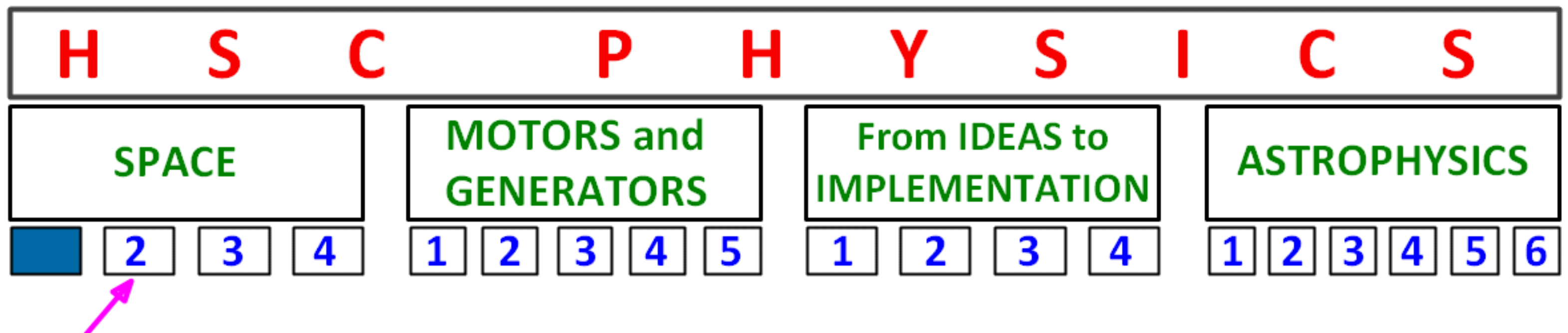


SPACE

1st Quarter; Module 1

PERIOD 9

Escape Velocity & "g" forces



ESCAPE VELOCITY - AS NEWTON OUTLINES

- ✓ A stone thrown from a tall tower will cover a considerable range before striking the ground.
- ✓ If it is thrown faster, it will travel further before stopping.
- ✓ If thrown faster still, it will have an even greater range.
- ✓ If thrown fast enough then, as the stone falls, the Earth's surface curves away, so that the falling stone never actually lands on the ground and orbits the Earth.

It was only a **thought experiment**, of course. He had no way of testing this idea but it does hit upon one important fact — that for any given altitude, there is a specific velocity required for any object to achieve a stable circular orbit.

- ✓ If this specific velocity is exceeded slightly, then the object will follow an elliptical orbit around the Earth.
- ✓ If the specific velocity is exceeded further still, then the object will follow a parabolic or hyperbolic path away from the Earth.

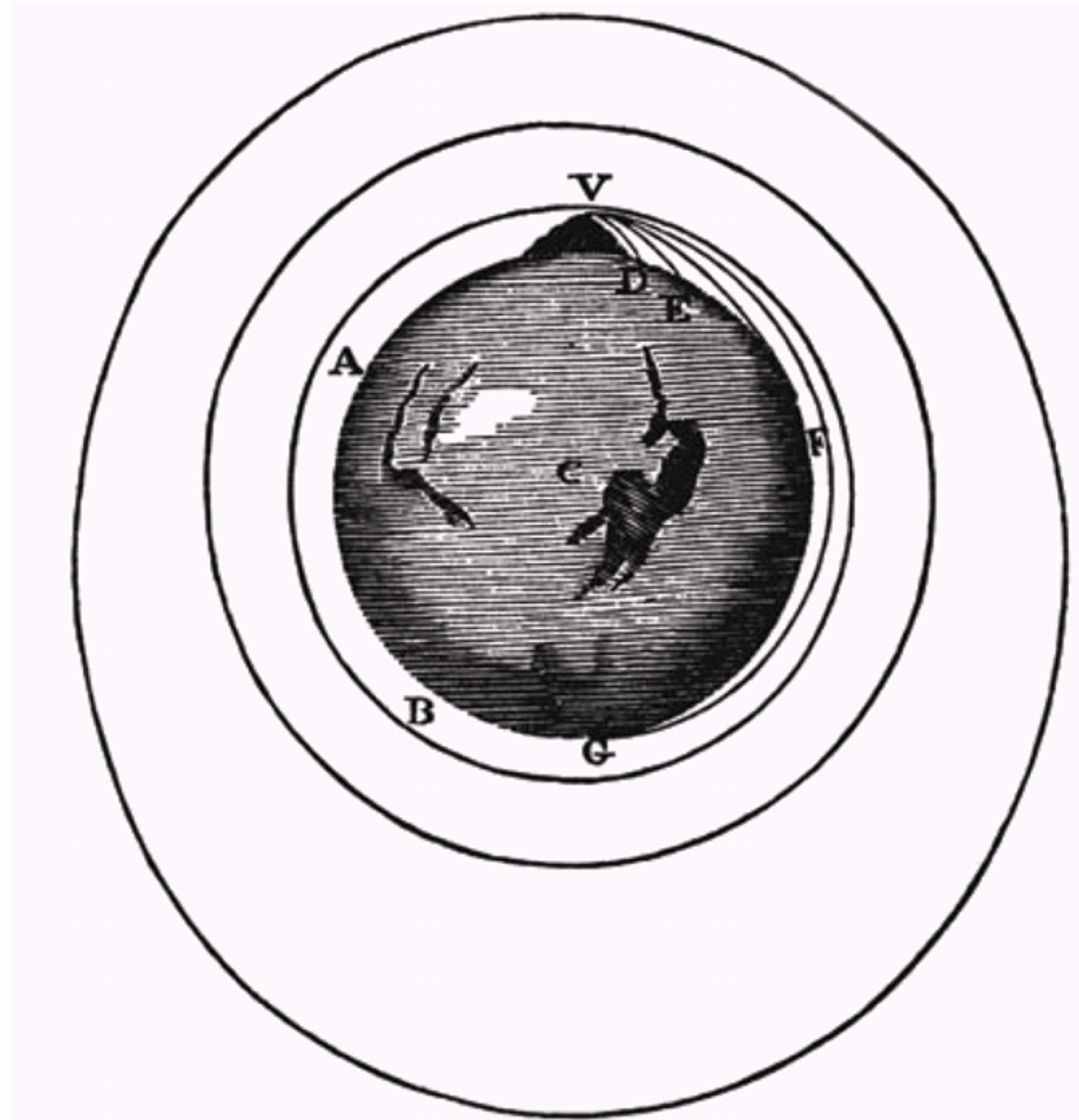


Figure 3.13 Newton's original sketch shows how a projectile that was fired fast enough would fall all the way around the Earth and become an Earth satellite.

ESCAPE VELOCITY - AS WE OUTLINE IT

$$E_{TOT \text{ surface}} = E_{TOT \text{ space}}$$

$$-\frac{GMm}{R} + \frac{1}{2}mv^2 = 0$$

$$V_{esc} = \sqrt{\frac{2GM}{R}}$$

=

Table 3.4 Data for the Sun, its eight planets and Earth's Moon

Body	Mass (kg)	Radius (m)	Period of rotation	Mean orbital radius (m)	Period of orbit	Av. orbital speed (km s ⁻¹)
Sun	1.98×10^{30}	6.95×10^8	24.8 days	NA	NA	NA
Mercury	3.28×10^{23}	2.57×10^6	58.4 days	5.79×10^{10}	88 days	47.8
Venus	4.83×10^{24}	6.31×10^6	243 days	1.08×10^{11}	224.5 days	35.0
Earth	5.98×10^{24}	6.38×10^6	23 h 56 min	1.49×10^{11}	365.25 days	29.8
Mars	6.37×10^{23}	3.43×10^6	24.6 h	2.28×10^{11}	688 days	24.2
Jupiter	1.90×10^{27}	7.18×10^7	9.8 h	7.78×10^{11}	11.9 years	13.1
Saturn	5.67×10^{26}	6.03×10^7	10 h	1.43×10^{12}	29.5 years	9.7
Uranus	8.80×10^{25}	2.67×10^7	10.8 h	2.87×10^{12}	84.3 years	6.8
Neptune	1.03×10^{26}	2.48×10^7	15.8 h	4.50×10^{12}	164.8 years	6.5
Moon	7.34×10^{22}	1.74×10^6	27.3 days	3.8×10^8	27.3 days	1.0

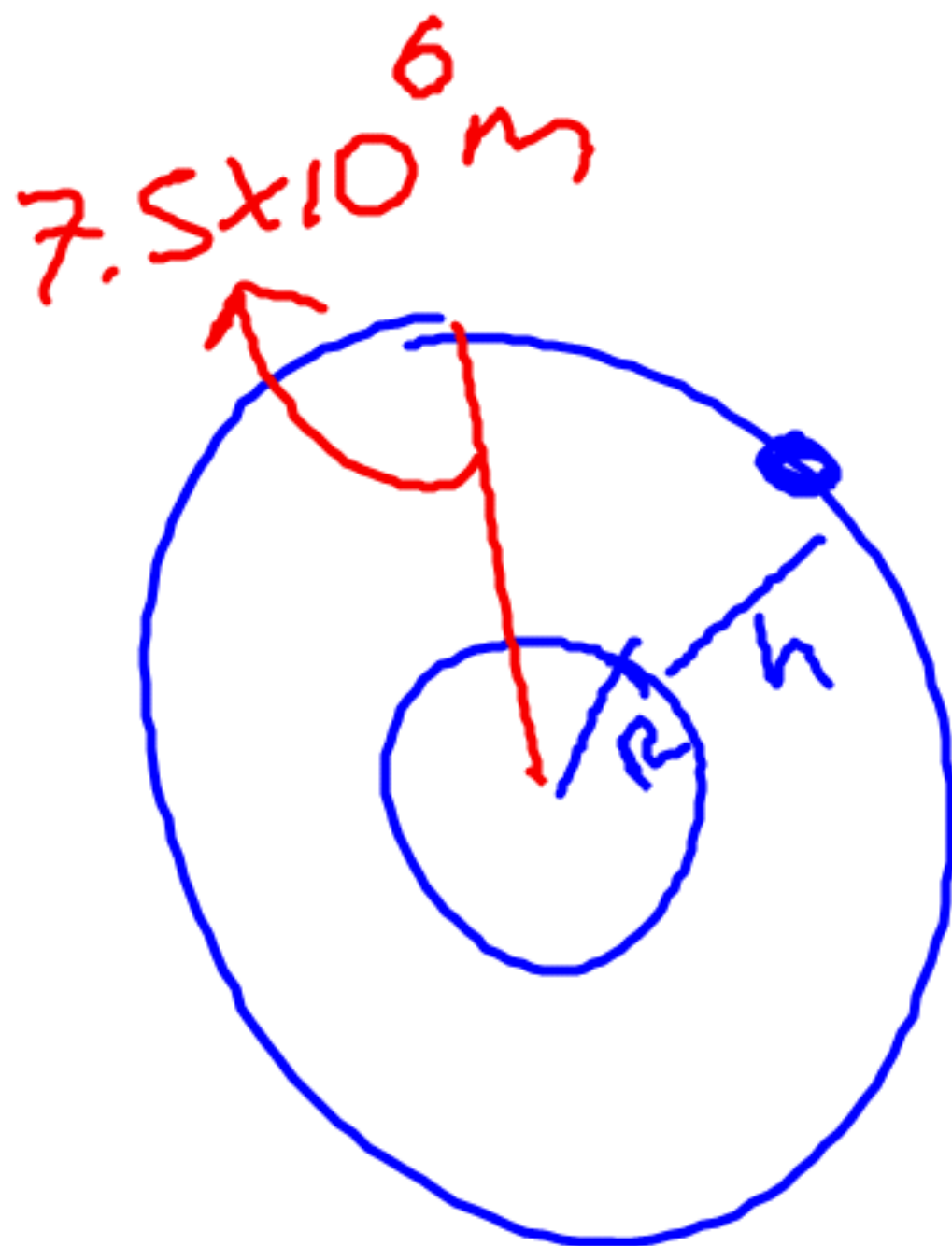
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Question 17 (6 marks)

A satellite of mass 150 kg is launched from Earth's surface into a uniform circular orbit of radius 7.5×10^6 m.

- (b) From this uniform circular orbit, the satellite can escape Earth's gravitational field when its kinetic energy is equal to the magnitude of the gravitational potential energy.

Use this relationship to calculate the escape velocity of the satellite.



$$E_{\text{TOT orbit}} = E_{\text{TOT space}}$$

$$-\frac{GMm}{d} + \frac{1}{2}mv^2 = 0$$

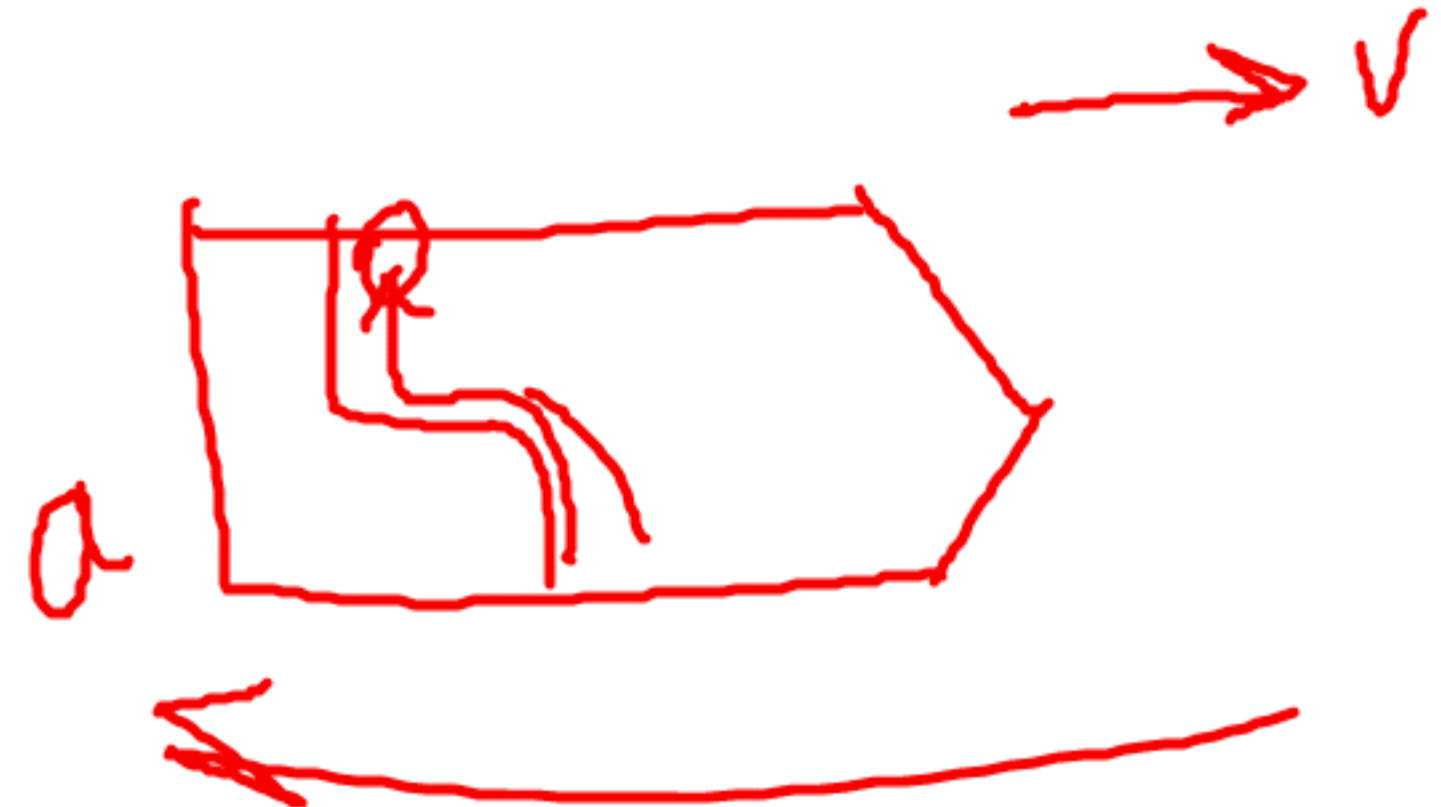
$$v = \sqrt{\frac{2GM}{d}} = 10300 \text{ m/s}$$

$$\begin{aligned} d &= R + h \\ &= 6380 \text{ km} + 7.5 \times 10^6 \text{ m} \\ &= 6.38 \times 10^6 \text{ m} + 7.5 \times 10^6 \text{ m} \\ &= 13.88 \times 10^6 \text{ m} \end{aligned}$$

g-FORCES

DID YOU EVER CONSIDER BECOMING AN ASTRANOUT?

Indicate the direction of the cabins after watching the videos



Example	g-force
The gyro rotors in Gravity Probe B and the free-floating proof masses in the TRIAD I navigation satellite	exactly 0 g
A ride in the Vomit Comet	approximately 0 g
Standing on the Moon at its equator	0.1654 g
Standing on the Earth at sea level—standard	1 g
Saturn V moon rocket just after launch	1.14 g
Space Shuttle, maximum during launch and reentry	3 g
High-g roller coasters	3.5–6.3 g
Formula One car, maximum under heavy braking	5 g
Standard, full aerobatics certified Glider	+7/-5 g
Apollo 16 on reentry	7.19 g
Typical max. turn in an aerobatic plane or fighter jet	9-12 g
Maximum for human on a rocket sled	46.2 g
Death or serious injury likely	>50 g
Sprint missile	100 g
Brief human exposure survived in crash	>100 g
Shock capability of mechanical wrist watches	>5000 g
Rating of electronics built into military artillery shells	15,500 g
9 × 19 Parabellum handgun bullet (average along the length of the barrel)	31,000 g
9 × 19 Parabellum handgun bullet, peak	190,000 g



WHAT IS THE MAXIMUM NUMBER OF G'S (G FORCE) THAT A HUMAN CAN ENDURE?

"Human tolerances depend on the magnitude of g-force, the length of time it is applied, the direction it acts, the location of application, and the posture of the body."

1) Vertical axis g-force:

- a) positive: untrained: 5 g; trained, with special suit: 9 g
- b) negative (drive blood to the head): - 3 g
- c) instantaneous: 40 g
- d) deadly: 100 g (record: 179 g)

2) Horizontal axis g-force "The human body is considerably more able to survive g-forces that are perpendicular to the spine."

Untrained humans:

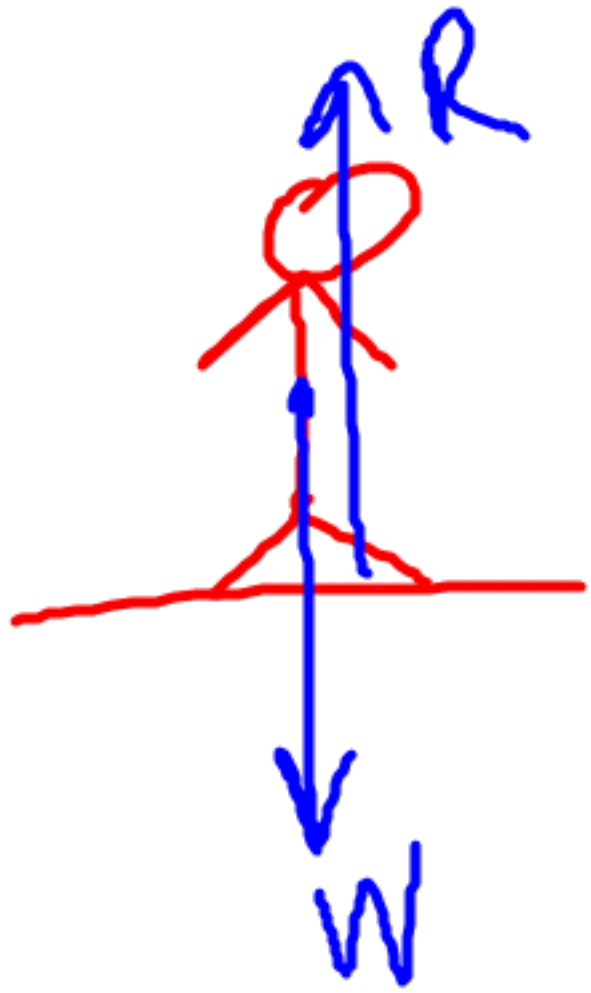
- a) pushing the body backwards: 17 g
- b) pushing the body forwards: 12 g

3) "Strongest g-forces survived by humans

Voluntarily: Colonel John Stapp in 1954 sustained 46.2 g in a rocket sled, while conducting research on the effects of human deceleration.

Involuntarily: Formula One racing car driver David Purley survived an estimated 179.8 g in 1977 when he decelerated from 173 km·h⁻¹ (108 mph) to 0 in a distance of 66 cm (26 inches) after his throttle got stuck wide open and he hit a wall."

$$g-f = \frac{R}{W} = \frac{\text{reaction force on you}}{\text{true weight (your weight on earth)}}$$



$$W = R \quad g-f = 1$$

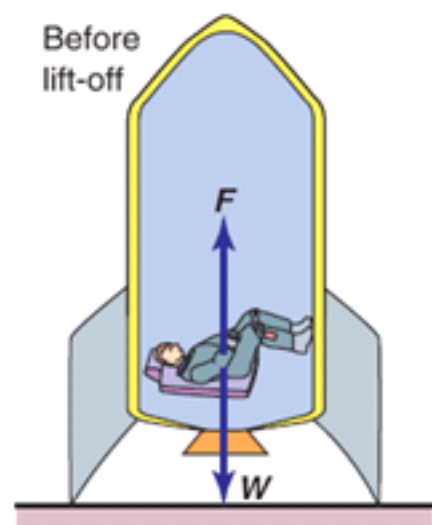


$$R > W$$

$$g-f = \frac{R}{W} > 1$$

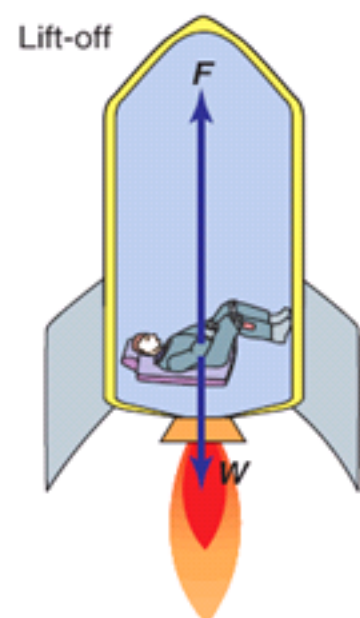
you feel heavier.

if $g-f > 1$, you feel heavier
 if $g-f < 1$, lighter
 if $g-f = 0$, no weight
 you feel weightless



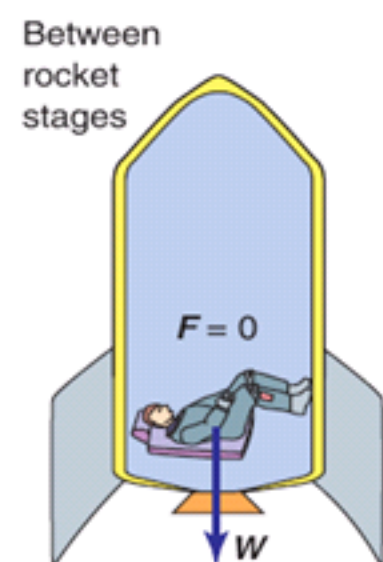
$$F = W$$

$$\therefore g \text{ force} = 1$$



$$F > W$$

$$\therefore g \text{ force} > 1$$



$$F = 0$$

$$\therefore g \text{ force} = 0$$

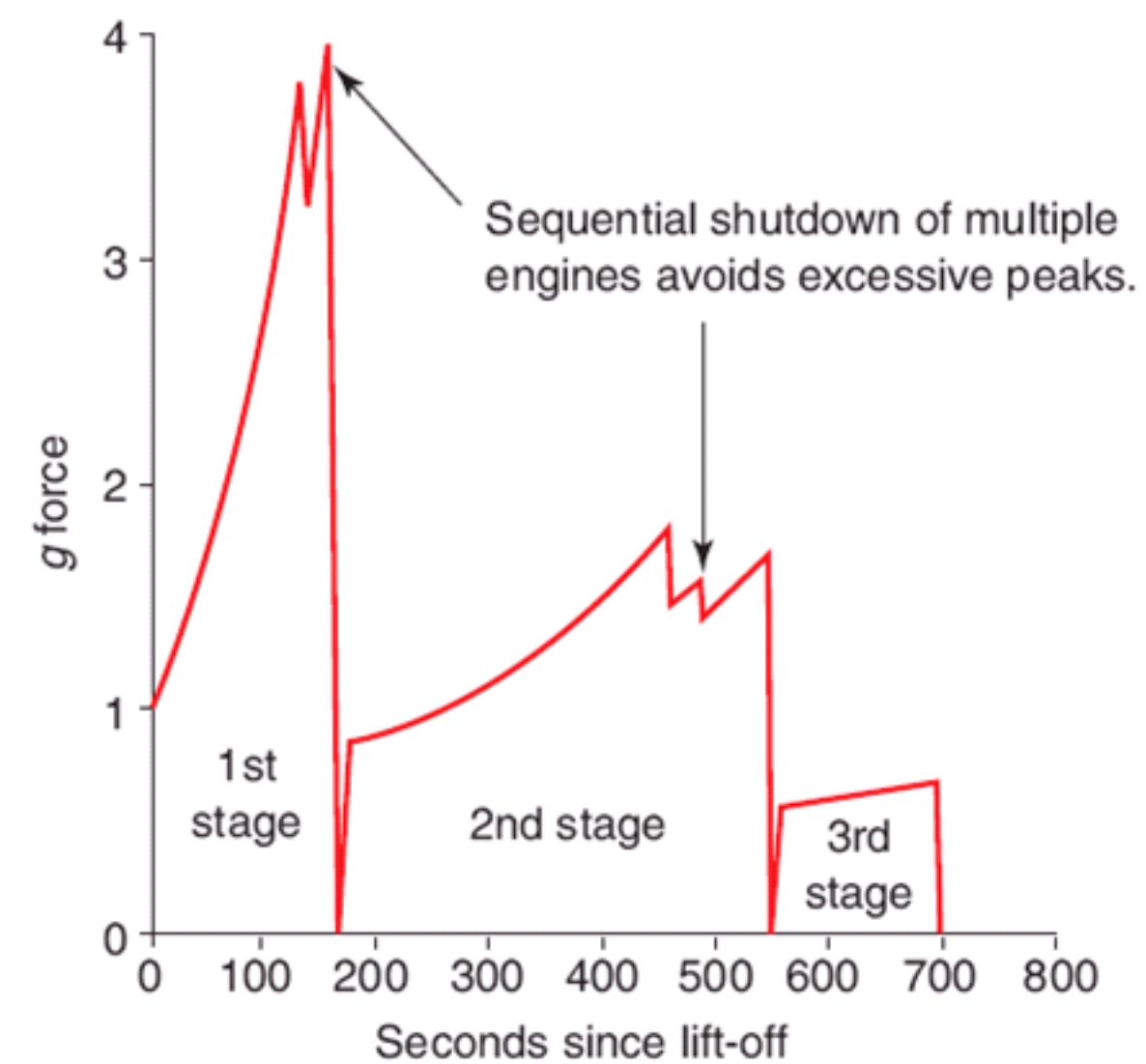


Figure 2.22 Variations in g forces during an Apollo-Saturn V launch

Calculating the g force on a model rocket

The model rocket has a pre-launch mass of 94.2 g, of which 6.24 g is solid propellant. It is able to deliver a thrust of 4.15 N for a period of 1.2 s.

Assuming that the rocket is fired directly up, determine:

- (a) the initial rate of acceleration and g force
- (b) the final rate of acceleration and g force just prior to exhaustion of the fuel.

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. PM Practice Booklet
2. All Questions in Period 7 & 8 BookletS
3. Chapter 2 Questions 1-17
4. Experiment 4 Report
5. Space 2 CSU notes
6. Read rest of the chapter



0 to 160 km/h in 0.86 seconds.
How many "g"?

http://www.youtube.com/watch?v=s4tuvOer_GI

<http://www.youtube.com/watch?v=GfZjN2ceVOI&NR=1>

NEXT PERIOD >

THE EFFECT OF EARTH'S ROTATION ON A LAUNCH

"If you are asked to build a launch pad in Australia, where would you build it?"

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.

SPACE 2

Many factors have to be taken into account to achieve a successful rocket launch, maintain a stable orbit and return to Earth

Students learn to:

- describe the trajectory of an object undergoing projectile motion within the Earth's gravitational field in terms of horizontal and vertical components
- describe Galileo's analysis of projectile motion
- explain the concept of escape velocity in terms of the:
 - gravitational constant
 - mass and radius of the planet
- outline Newton's concept of escape velocity
- identify why the term 'g forces' is used to explain the forces acting on an astronaut during launch
- discuss the effect of the Earth's orbital motion and its rotational motion on the launch of a rocket
- analyse the changing acceleration of a rocket during launch in terms of the:
 - Law of Conservation of Momentum
 - forces experienced by astronauts
- analyse the forces involved in uniform circular motion for a range of objects, including satellites orbiting the Earth
- compare qualitatively low Earth and geo-stationary orbits
- define the term orbital velocity and the quantitative and qualitative relationship between orbital velocity, the gravitational constant, mass of the central body, mass of the satellite and the radius of the orbit using Kepler's Law of Periods
- account for the orbital decay of satellites in low Earth orbit
- discuss issues associated with safe re-entry into the Earth's atmosphere and landing on the Earth's surface
- identify that there is an optimum angle for safe re-entry for a manned spacecraft into the Earth's atmosphere and the consequences of failing to achieve this angle

SPACE 2

Many factors have to be taken into account to achieve a successful rocket launch, maintain a stable orbit and return to Earth

Students:

- solve problems and analyse information to calculate the actual velocity of a projectile from its horizontal and vertical components using:

$$v_x^2 = u_x^2$$

$$v = u + at$$

$$v_y^2 = u_y^2 + 2a_y\Delta y$$

$$\Delta x = u_x t$$

$$\Delta y = u_y t + \frac{1}{2} a_y t^2$$

- perform a first-hand investigation, gather information and analyse data to calculate initial and final velocity, maximum height reached, range and time of flight of a projectile for a range of situations by using simulations, data loggers and computer analysis
- identify data sources, gather, analyse and present information on the contribution of one of the following to the development of space exploration: Tsiolkovsky, Oberth, Goddard, Esnault-Pelterie, O'Neill or von Braun
- solve problems and analyse information to calculate the centripetal force acting on a satellite undergoing uniform circular motion about the Earth using

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

- solve problems and analyse information using:

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

