



Unit 7 • Motion and Force: gravitation and gravity

Give the marks for the points in the marking scheme; an answer in other words that says the same is right.

1 Key words

1. gravitation
2. gravity
3. G
4. Cavendish
5. centers
6. acceleration due to gravity
7. poles
8. mass

K • 4

Each carries 0.5 mark.

2 Label the diagram

- | | |
|---------------------------|----------------------------|
| 1. glass tube | 4. air pumped out (vacuum) |
| 2. coin | 5. pump |
| 3. feather: slowed by air | 6. fall together |

K • 3

Each carries 0.5 mark.

3 Multiple choice

- i. a. $F \propto 1/d^2$ K • 1

Newton's law: the force is inversely proportional to the square of the distance.

- ii. b. it becomes four times as large U • 1

$F \propto m_1 m_2$: $2 \times 2 = 4$, so the force becomes 4 times as large.

- iii. b. The value of g decreases as the height above the Earth's surface increases. U • 1

$g_1 = GM/(R+h)^2$ gets smaller as h grows. g is more at the poles, and least at the highest places. As for going down: in the simple picture used in school, g decreases below the surface too. (A surprise: in the real Earth, whose core is far denser than its rocky outer layers, g actually rises slightly as you go down, until you reach the core. But the answer expected here is the second option.)

- iv. c. 200 N A • 1

At a height equal to the radius, the object is $2R$ from the center. $\text{Weight} \propto 1/d^2$, so it becomes $800 \div 2^2 = 200 \text{ N}$.

- v. b. 4.9 m/s^2 A • 1

$g = GM/R^2$: mass $\times 2$, radius² $\times 4$, so $g \times 2/4 = \frac{1}{2} \times 9.8 = 4.9 \text{ m/s}^2$.

4 Very short answers

- a. MARKING SCHEME K • 1

✓ The gravitational force between two masses of 1 kg each whose centers are 1 m apart.

- b. MARKING SCHEME K • 1

✓ $\text{N m}^2/\text{kg}^2$ written.

- c. MARKING SCHEME U • 1

✓ A freely falling object gains a speed of 9.8 m/s every second.



5 Short answers

a. MARKING SCHEME

U • 2

- ✓ Any one difference, e.g. G is the force between two 1 kg masses 1 m apart; g is the acceleration of a freely falling object due to gravity.
- ✓ Any second difference, e.g. G is the same everywhere in the universe (unit $\text{N m}^2/\text{kg}^2$); g changes from place to place (unit m/s^2).

b. MARKING SCHEME

U • 2

- ✓ $g = GM/R^2$ depends on the square of the radius as well as on the mass.
- ✓ Jupiter's radius is about 11 times the Earth's, so R^2 is 121 times as large, and g is only $319 \div 121 \approx 2.6$ times the Earth's.

c. MARKING SCHEME

U • 2

- ✓ The Earth is flattened at the poles, so the poles are closer to the Earth's center than the equator.
- ✓ Since $g \propto 1/R^2$, g is larger at the poles (9.83 m/s^2) than at the equator (9.78 m/s^2), so the object there speeds up faster.

6 Long answer

ANSWER

U • 4

Let an object of mass m be on the surface of the Earth, of mass M and radius R . By

Newton's law of gravitation, the force on it is $F = \frac{GMm}{R^2}$... (i).

This force gives it an acceleration g , so by Newton's second law, $F = mg$... (ii).

From (i) and (ii): $mg = \frac{GMm}{R^2}$, so $g = \frac{GM}{R^2}$.

G is a constant, and the mass M of the Earth is fixed, so $g \propto \frac{1}{R^2}$.

MARKING SCHEME

- ✓ By Newton's law of gravitation, the force on an object of mass m on the surface is $F = GMm/R^2$ (i).
- ✓ By Newton's second law, this force gives it an acceleration g : $F = mg$ (ii).
- ✓ From (i) and (ii), $mg = GMm/R^2$, so $g = GM/R^2$.
- ✓ G and the planet's mass M are constant, so $g \propto 1/R^2$.

7 Numerical problems

a. ANSWER

A • 2

$$F = \frac{G m_1 m_2}{d^2} = \frac{6.67 \times 10^{-11} \times 20 \times 40}{5^2} = \frac{6.67 \times 10^{-11} \times 800}{25} = 2.134 \times 10^{-9} \text{ N}$$

$$F = 2.13 \times 10^{-9} \text{ N}$$

MARKING SCHEME

- ✓ $F = Gm_1m_2/d^2$ with 20 kg, 40 kg and 5 m put in.
- ✓ $F = 2.13 \times 10^{-9} \text{ N}$.

b. ANSWER

A • 4

$$d = R + h = 6371 \text{ km} + 20,200 \text{ km} = 26,571 \text{ km} = 2.6571 \times 10^7 \text{ m}.$$

$$g_1 = GM/(R + h)^2 = (6.67 \times 10^{-11} \times 5.972 \times 10^{24}) \div (2.6571 \times 10^7)^2 = 39.83 \times 10^{13} \div 7.060 \times 10^{14} = 0.56 \text{ m/s}^2.$$

MARKING SCHEME

- ✓ Distance from the center: $R + h = 26,571 \text{ km} = 2.6571 \times 10^7 \text{ m}$.
- ✓ Formula $g_1 = GM/(R + h)^2$ written.
- ✓ Values put in correctly.
- ✓ $g_1 = 0.56 \text{ m/s}^2$.



8 Think

ANSWER

HA · 2

Also 2 m/s^2 . The acceleration due to gravity at a point is $g = GM/d^2$, which depends only on the mass M of the body pulling and the distance d from its center, not on the mass of the falling object. The 10 kg object is pulled 10 times harder, but it is also 10 times harder to speed up, so its acceleration is the same.

MARKING SCHEME

- ✓ Also 2 m/s^2 : the acceleration due to gravity at a point, $g = GM/d^2$, depends only on the mass of the body pulling and the distance from its center.
- ✓ The 10 kg object is pulled 10 times harder, but it is also 10 times harder to speed up, so the mass cancels.

9 Activity: Paper, paper ball and stone (Activity 7.3)

(not marked)

WHAT STUDENTS SHOULD FIND

The paper ball and the stone land together; the flat sheet drifts down last. The flat sheet and the ball have the same mass but fall differently, and the ball and the stone have very different masses but fall together, so mass doesn't decide how fast things fall: the large flat sheet meets much more air resistance. On the Moon, which has no air, all three would land together.

See it at Science Playground

Exhibits and plants at the center, Bhaktapur, that go with this unit. Book a class visit at science-playground.com/booking.

- **Flying Paper Shapes** (exhibit): Drop the paper shapes: air pushes up on them, so they fall far slower than a stone.

Marks by level	Knowledge	Understanding	Application	Higher ability	Total
Marks	10	13	8	2	33





Unit 7 • Motion and Force: mass, weight and free fall

Give the marks for the points in the marking scheme; an answer in other words that says the same is right.

1 Key words

1. mass
2. beam balance
3. weight
4. newton
5. spring balance
6. free fall
7. terminal velocity
8. weightlessness

K • 4

Each carries 0.5 mark.

2 Label the diagram

- | | | |
|---------------------------------|--------------------------------------|-------|
| 1. spring balance | 4. reads 0 | K • 3 |
| 2. iron frame | 5. thread goes loose | |
| 3. stone pulls the thread tight | 6. stone stays put, pulls on nothing | |

Each carries 0.5 mark.

3 Multiple choice

- i. c. Kechana Kawal in Jhapa

U • 1

Kechana Kawal is the **lowest point in Nepal**, less than 100 m above sea level, so it is closest to the Earth's center; g , and so your weight, is greatest there. (All four places are at much the same latitude.)

- ii. c. mass is still 70 kg, his weight is about 6 times less

U • 1

Mass is the amount of matter in him, which doesn't change by traveling. Weight is $W = mg$, and g on the Moon is about a sixth of the Earth's: $70 \times 1.62 = 113 \text{ N}$ instead of 686 N.

- iii. a. 124.74 N

A • 1

His mass: $m = W/g = 750 \div 9.8 = 76.53 \text{ kg}$. On the Moon: $W = mg = 76.53 \times 1.63 = 124.74 \text{ N}$.

- iv. b. the velocity increases uniformly

U • 1

The acceleration g is **constant**, so the velocity goes up by the same 9.8 m/s every second: it increases **uniformly**. The distance covered each second grows (4.9 m, then 14.7 m, then 24.5 m), so it is not uniform.

- v. c. zero

A • 1

The girl and the scale fall together with acceleration g , so she doesn't press on it at all: the scale reads zero, just as the spring balance did in Activity 7.7. (Lifts have safety brakes that stop them falling; don't worry.)

4 Very short answers

- a. MARKING SCHEME

K • 1

✓ The state of an object in free fall, in which it presses on nothing and a spring balance falling with it reads zero.

- b. MARKING SCHEME

K • 1

✓ When gravity is the only force acting on it (no air resistance or upthrust, as in a vacuum).



- c. MARKING SCHEME K · 1
✓ $v^2 = u^2 + 2gh$ written.

5 Short answers

- a. MARKING SCHEME U · 2
✓ Any one difference, e.g. mass is the quantity of matter in an object; weight is the force with which a planet pulls it towards its center.
✓ Any second difference, e.g. mass is measured in kg and stays the same everywhere; weight is measured in N and changes with g ($W = mg$).
- b. MARKING SCHEME U · 2
✓ A falling body keeps speeding up: it lands with $v = \sqrt{2gh}$, which is larger the greater the height.
✓ A larger speed stopped in the same short moment needs a much larger force on the body, so the injury is greater.
- c. MARKING SCHEME U · 2
✓ Both have the same mass, but the flat sheet has a much larger surface, so it meets much more air resistance.
✓ The compact ball meets little air resistance and falls almost freely, so it lands first.

6 Long answer

ANSWER

A · 4

When the parachute opens, its large canopy meets a large air resistance, which grows with speed. Soon the air resistance becomes equal to the parachutist's weight. The net force is then zero, so the acceleration is zero, and the parachutist falls at a small, steady speed (the terminal velocity, about 5 m/s), which allows a safe landing.

On the Moon, it isn't possible: there is no atmosphere, so there is no air resistance. The parachute can't slow the fall; the astronaut would be in free fall, keep speeding up, and hit the surface fast. (Spacecraft land on the Moon using rockets.)

MARKING SCHEME

- ✓ The large canopy of the opened parachute meets a large air resistance, which grows with speed.
- ✓ Soon the air resistance equals the weight; the net force and the acceleration become zero, and the parachutist falls at a small steady speed (terminal velocity), which is safe.
- ✓ Not possible on the Moon: it has no atmosphere, so there is no air resistance.
- ✓ The astronaut would be in free fall, keep speeding up and hit the surface fast (landers use rockets).

7 Numerical problems

- a. ANSWER A · 2
She can push up with the same greatest force in both places, so the weight lifted is the same: $m \times 3.75 = 100 \times 9.8$, so $m = 980 \div 3.75 = 261.33$ kg.

MARKING SCHEME

- ✓ Weight lifted is the same: $m \times 3.75 = 100 \times 9.8$.
- ✓ $m = 980 \div 3.75 = 261.33$ kg.



b. ANSWER

A · 4

$u = 0$, $h = 15$ m, $g = 9.8$ m/s².

Time: $h = \frac{1}{2}gt^2$, so $t = \sqrt{(2h/g)} = \sqrt{(30 \div 9.8)} = \sqrt{3.061} = 1.75$ s.

Velocity: $v = u + gt = 0 + 9.8 \times 1.75 = 17.15$ m/s (or $v = \sqrt{(2gh)} = \sqrt{294} = 17.15$ m/s).

MARKING SCHEME

✓ $u = 0$; $h = \frac{1}{2}gt^2$, so $t = \sqrt{(2h/g)} = \sqrt{(30/9.8)}$.

✓ $t = 1.75$ s.

✓ $v = u + gt = 0 + 9.8 \times 1.75$ (or $v = \sqrt{(2gh)}$).

✓ $v = 17.15$ m/s.

8 Think

ANSWER

HA · 2

No, it would not work. A beam balance compares the object with standard masses on the other pan. Moving to the Terai, g increases for the oranges and for the standard masses by exactly the same factor, so the beam balances at the same reading. A beam balance measures **mass**, which doesn't change, so 10 kg bought is 10 kg sold, and there is no profit.

(With a **digital scale** it would be different. A digital or spring scale measures **weight** and shows it as kilograms. In the mountains, where g is a little smaller, the oranges press less and read slightly lighter; in the Terai the same oranges read slightly heavier, so the trick would "work", but only by about 0.1% for a 3000 m difference in height: about 10 g on 10 kg. And a scale set up for one place should be adjusted for another.)

MARKING SCHEME

✓ **No:** a beam balance compares the oranges with standard masses, and g changes by the same factor for both, so it measures mass.

✓ The mass of the oranges is the same in the mountains and the Terai, so 10 kg bought is 10 kg sold, and there is no profit.

9 Activity: Measure your reaction time with a ruler

(not marked)

WHAT STUDENTS SHOULD FIND

Most people catch the ruler after it falls 10 to 25 cm, a reaction time of about 0.14 to 0.23 s (15 cm gives 0.175 s). The ruler is let go from rest ($u = 0$) and air hardly slows it over such a short drop, so it falls freely with acceleration g , and $h = \frac{1}{2}gt^2$.

Marks by level	Knowledge	Understanding	Application	Higher ability	Total
Marks	10	9	12	2	33

