

SURFING

VCE PHYSICS

3

Unit 3 How Do Fields Explain Motion and Electricity?

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Introduction

This book covers the Physics content specified in the Victorian Certificate of Education Physics Study Design. Sample data has been included for suggested experiments to give you practice to reinforce practical work in class.

Each book in the *Surfing* series contains a summary, with occasional more detailed sections, of all the mandatory parts of the syllabus, along with questions and answers.

All types of questions – multiple choice, short response, structured response and free response – are provided. Questions are written in exam style so that you will become familiar with the concepts of the topic and answering questions in the required way.

Answers to all questions are included.

A topic test at the end of the book contains an extensive set of summary questions. These cover every aspect of the topic, and are useful for revision and exam practice.

Words To Watch

account, account for State reasons for, report on, give an account of, narrate a series of events or transactions.

analyse Interpret data to reach conclusions.

annotate Add brief notes to a diagram or graph.

apply Put to use in a particular situation.

assess Make a judgement about the value of something.

calculate Find a numerical answer.

clarify Make clear or plain.

classify Arrange into classes, groups or categories.

comment Give a judgement based on a given statement or result of a calculation.

compare Estimate, measure or note how things are similar or different.

construct Represent or develop in graphical form.

contrast Show how things are different or opposite.

create Originate or bring into existence.

deduce Reach a conclusion from given information.

define Give the precise meaning of a word, phrase or physical quantity.

demonstrate Show by example.

derive Manipulate a mathematical relationship(s) to give a new equation or relationship.

describe Give a detailed account.

design Produce a plan, simulation or model.

determine Find the only possible answer.

discuss Talk or write about a topic, taking into account different issues or ideas.

distinguish Give differences between two or more different items.

draw Represent by means of pencil lines.

estimate Find an approximate value for an unknown quantity.

evaluate Assess the implications and limitations.

examine Inquire into.

explain Make something clear or easy to understand.

extract Choose relevant and/or appropriate details.

extrapolate Infer from what is known.

hypothesise Suggest an explanation for a group of facts or phenomena.

identify Recognise and name.

interpret Draw meaning from.

investigate Plan, inquire into and draw conclusions about.

justify Support an argument or conclusion.

label Add labels to a diagram.

list Give a sequence of names or other brief answers.

measure Find a value for a quantity.

outline Give a brief account or summary.

plan Use strategies to develop a series of steps or processes.

predict Give an expected result.

propose Put forward a plan or suggestion for consideration or action.

recall Present remembered ideas, facts or experiences.

relate Tell or report about happenings, events or circumstances.

represent Use words, images or symbols to convey meaning.

select Choose in preference to another or others.

sequence Arrange in order.

show Give the steps in a calculation or derivation.

sketch Make a quick, rough drawing of something.

solve Work out the answer to a problem.

state Give a specific name, value or other brief answer.

suggest Put forward an idea for consideration.

summarise Give a brief statement of the main points.

synthesise Combine various elements to make a whole.

VCE PHYSICS

3

Area of Study 1

How Do Things Move Without Contact?



1 Newton's Laws of Gravitation

Newton's laws of gravitation

1. Every object in the Universe attracts every other object with a gravitational force.
2. This force is directly proportional to the masses of the objects, and
3. This force is inversely proportional to the square of the distance between them.

$$F_g = \frac{Gm_1m_2}{r^2}$$

G = the **universal gravitational constant**

$$= 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$$

r = the distance between the centres of the two (distance apart plus radii)

m_1, m_2 = masses of the two objects

Acceleration due to gravity

If we apply this idea to a mass close to the surface of the Earth, then the formula becomes: $F_g = \frac{Gm_1M_{\text{Earth}}}{r^2} = m_1g$

r = radius of Earth plus height object is above the surface (average radius = $6.378 \times 10^6 \text{ m}$)

Gravitational acceleration on other planets or moons

The gravitational force on an object on another planet (or moon) is given by: $F_g = \frac{Gm_{\text{object}}M_{\text{planet}}}{(r_{\text{planet}})^2} = m_{\text{object}}g_{\text{planet}}$

$$\text{From this we get: } g_{\text{planet}} = \frac{GM_{\text{planet}}}{(r_{\text{planet}})^2}$$

Gravitational attraction at any distance from a planet or moon

This is simply a matter of using the distance of the position in space from the centre of the planet or moon in the equation.

$$\text{That is, } g_{\text{point in space}} = \frac{GM_{\text{planet}}}{(\text{distance from planet})^2}$$

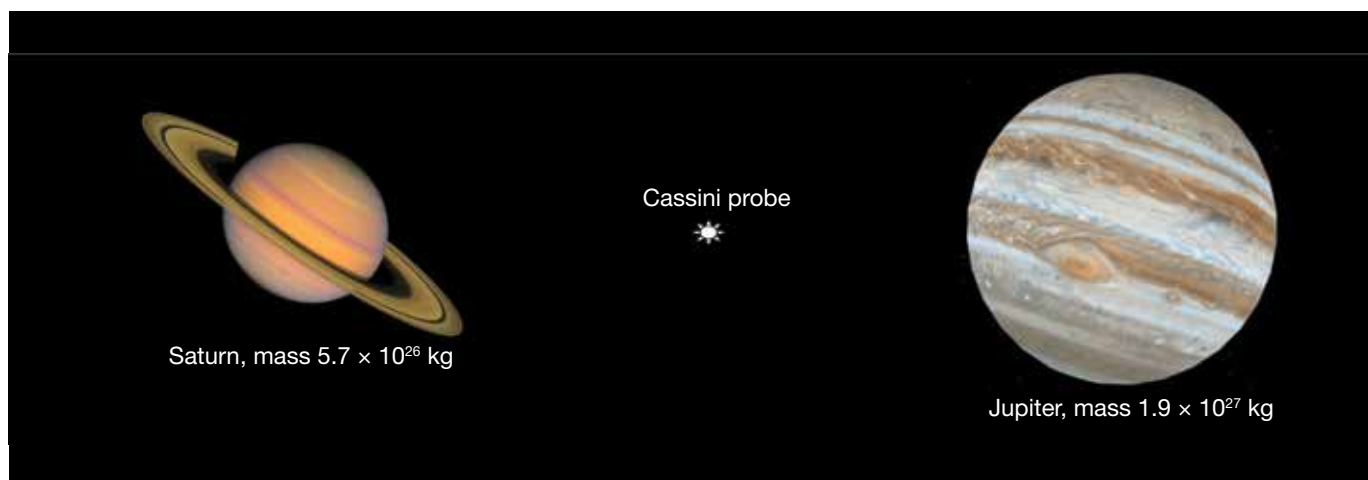
Ratio of accelerations on heavenly objects

From this last equation, extending it to two different heavenly objects (for example, comparing gravitational acceleration on Earth with that on any other planet or moon), we get: $g_{\text{Earth}} = \frac{GM_{\text{Earth}}}{(r_{\text{Earth}})^2}$ and $g_{\text{planet}} = \frac{GM_{\text{planet}}}{(r_{\text{planet}})^2}$

$$\text{Rearranging these, we get: } \frac{g_{\text{Earth}}}{g_{\text{planet}}} = \frac{M_{\text{Earth}}(r_{\text{planet}})^2}{M_{\text{planet}}(r_{\text{Earth}})^2}$$

QUESTIONS

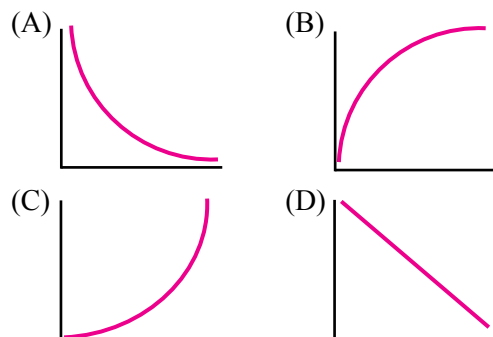
- The radius of the Earth is 6378 km and its mass is 5.974×10^{24} kg. Calculate the acceleration due to gravity on top of Mount Everest, 8800 m above sea level.
- You have a mass of 60 kg. Predict your 'loss' in weight at the top of Sydney Tower, 305 m above sea level.
- Calculate the gravitational force between you and another person (both mass 60 kg), 5 m apart.
- The Moon's mass is 7.35×10^{22} kg. Its diameter is 3467 km. Compare its gravitational acceleration to that of Pluto, mass 1.27×10^{22} kg, diameter 2320 km.
- The mass of Ganymede is 1.5×10^{23} kg and its diameter is about 5270 km.
 - Calculate the acceleration due to gravity on the surface of Ganymede.
 - How does this compare with Earth's gravity?
 - Calculate the weight of a 10 kg mass on Ganymede's surface.
- Two moons have masses M and $2M$ and radii R and $2R$ respectively. Compare their accelerations due to gravity.
- Predict the effect on the gravitational force between two objects of:
 - Doubling the distance between them.
 - Doubling both masses.
 - Halving one mass and the distance between them.
- Compare the gravitational force of attraction between masses X and Y, 10 kg and 20 kg respectively, 5 m apart, on the Moon ($g = 1.6 \text{ m s}^{-2}$) and on Earth.
- A space shuttle is orbiting Earth in a gravitational field of strength 8.9 N kg^{-1} . The mass of the Earth is 6×10^{24} kg and its radius is 6380 km.
 - What is the altitude of the shuttle?
 - What is the weight of a 65 kg astronaut in this shuttle?
- At some point between the Moon and the Earth will be a zero gravity point. Given the mass of the Moon and Earth as 7.35×10^{22} kg and 6×10^{24} kg respectively and the distance between their centres as 385 000 km, calculate how far this point is from Earth.
- A satellite in orbit around a planet at a distance of 8.0×10^7 km has 3.0×10^{10} J of kinetic energy. What is the weight of this satellite?
- An astronaut weighs W on Earth. What would the astronaut weigh on a planet which had twice the mass of Earth and half its radius?
- An object of mass 12 kg weighs 156 N on planet X. What is the magnitude of the acceleration due to gravity on planet X?
- An object has a mass of 9.0 kg on Earth and a weight of 101.43 N on Saturn. According to this data, what is the value of the acceleration due to gravity on Saturn?
- An object weighs 147 N on Earth and 84 N on planet X. What is the acceleration due to gravity on planet X?
- In 2002 the space probe *Cassini*, mass 2200 kg, was directly between Saturn and Jupiter as shown in the diagram (not to scale).



Find the net force on *Cassini* when it is 4.2×10^{11} km from Jupiter and 3.9×10^{11} km from Saturn.

17. Which of the following statements does *not* relate to Newton's laws of gravitation?
- (A) A gravitational force exists between all masses.
 (B) This gravitational force depends on the masses of the objects.
 (C) The gravitational force depends inversely on the square of the distance between the objects.
 (D) The gravitational force depends on the universal gravitational constant.

18. Which graph best shows the relationship between gravitational force and distance from the centre of a planet?



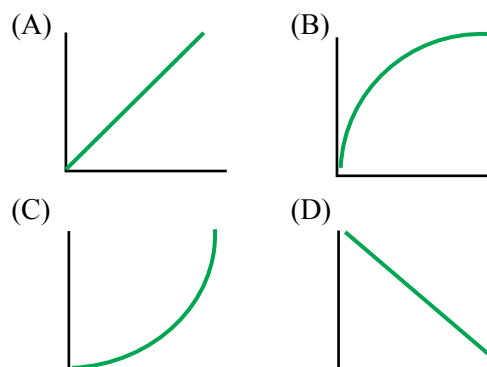
19. (a) What is the gravitational force between two objects, each of mass 40 kg when they are 6 m apart?

- (A) 1.78×10^{-8} N
 (B) 2.96×10^{-9} N
 (C) 4.45×10^{-10} N
 (D) 7.41×10^{-11} N

- (b) What would the new force be if both masses and the distance between them were doubled?

20. Two planets, X and Y have masses $4M$ and $9M$ and diameters $8R$ and $18R$ respectively. What is the ratio of their gravitational forces on their surfaces?
- (A) 2 : 9 (B) 4 : 9 (C) 9 : 4 (D) 16 : 81

21. Which graph best shows the relationship between gravitational force and the mass of a planet?



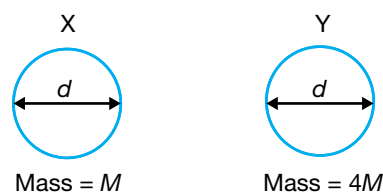
22. An astronaut has weight W on planet X. What would be his weight on planet Y which has half the mass and half the diameter of X?

- (A) $0.25W$ (B) $0.5W$ (C) $2W$ (D) $4W$

23. An astronaut in orbit 6000 km above the Earth experiences a gravitational force of F . His spaceship moves to a 12 000 km orbit. What is the new gravitational force the astronaut experiences?

- (A) $0.25F$ (B) $0.44F$ (C) $0.5F$ (D) $2.25F$

24. Consider the two planets, X and Y shown below.



The gravitational force on X due to Y is F . What is the gravitational force on Y due to X?

- (A) $0.25F$ (B) $0.5F$ (C) F (D) $4.0F$

2 Gravitational Field

A **field** is a region in which some quantity in physics has a value at every point in the region. For example, temperature has a value at any point in a room, so we could refer to the temperature field of the room. Air pressure has a value anywhere in the atmosphere, so we could refer to the pressure field of the atmosphere. Fields in which certain objects experience a force are known as **force fields**. The most common force fields you will meet in this course are gravitational, magnetic and electric fields.

- A **gravitational field** is a region in which a mass will experience a force.
- A **magnetic field** is a region in which a magnetic substance will experience a force.
- An **electric field** is a region in which an electric charge will experience a force.

Fields are found around objects similar to the ones they affect. Gravitational fields are found around all masses. Magnetic fields are associated with magnets, and electric fields are found around electrostatic charges, or between charged electric plates.

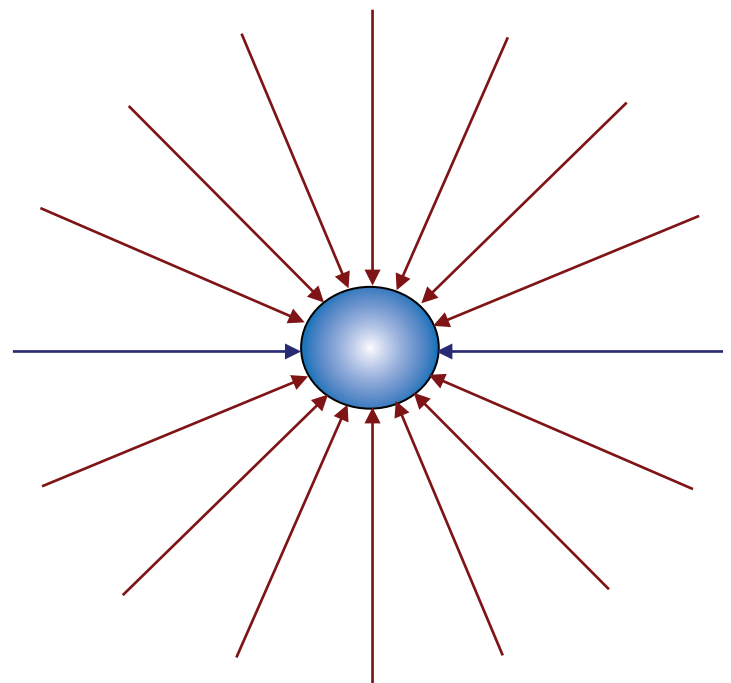
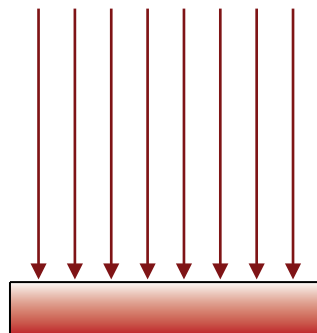
A mass experiences a force in a gravitational field, directed downwards, towards the centre of the Earth.

Being a vector quantity, gravitational field (like all other fields) can be represented by field lines. If we are close to the Earth's surface, then the field lines can be considered parallel to each other (a), but if we are some distance from Earth, then the field lines are radial (b).

Note that the direction of the field is given by the direction of the vector arrows, and the relative strength of the field is represented by how close the vector arrows are together.

Note that in (a), the field lines are drawn equidistant from each other, indicating that we accept the value of the gravitational field near the Earth's surface as uniform in magnitude.

(a) Gravitational field lines close to the surface can be taken as parallel to each other.



(b) Gravitational field lines away from Earth are radial towards the centre of the Earth.

Gravitational field (g) is the gravitational force per unit mass acting on a mass at that point.

Where g = gravitational field strength in m s^{-2}

F_G = gravitational force on mass in N

m = mass in kg

$$g = \frac{F_G}{m}$$

The average surface value of the gravitational field on the Earth's surface is 9.8 m s^{-2} . Possible reasons for variations in the actual value of the gravitational field at a point on the Earth's surface include the following.

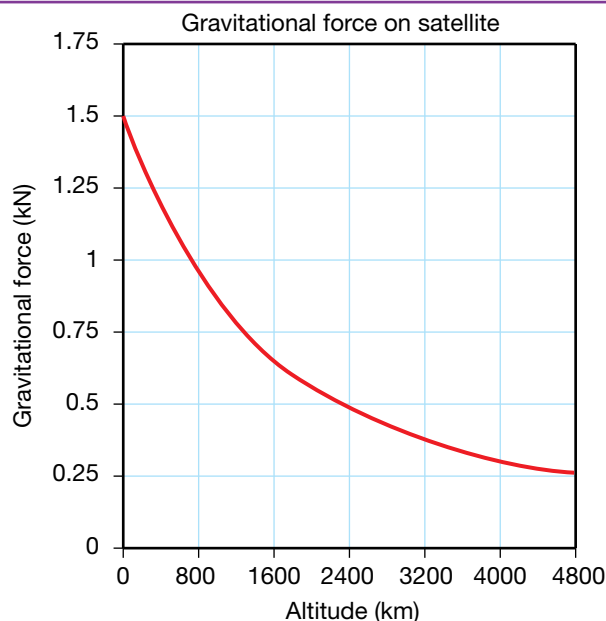
- The Earth's crust varies in structure, thickness and density. Crust under oceans is thinner than continental crust. Continental crust is thickest under mountains. Density changes due to the presence of minerals, oil or gas trapped in rock structures. These variations influence local values of g .
- The Earth's globe is flattened at the poles. This means that the distance of the surface from the centre of the Earth is less at the poles, which changes the local value of g .
- The spin of the Earth also affects the value of g . At the equator, the spin effect is greatest. As you travel from the equator to the poles, the spin effect on g shrinks to zero.
- Altitude above the surface of a planet decreases g which becomes zero at an infinite distance.

QUESTIONS

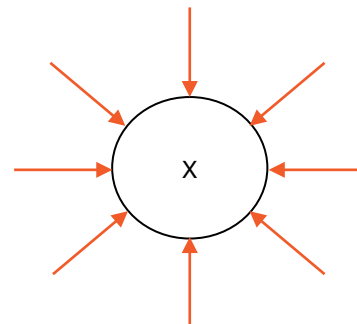
1. Copy the table into your book and complete it to indicate the changes in the value of gravitational field strength for each of the factors indicated, giving reasons why these changes occur.

Factor (position on Earth)	Value of g (9.8, larger than 9.8, smaller than 9.8)	Explanation
Sea level, middle of Australia		
Sea level, on boat in middle of ocean		
Sea level at the equator		
Sea level, London		
Sea level, North Pole		
Equator, top of high mountain		
Equator, deep down mine shaft		
In plane, flying over ocean		

2. Given the mass of the Earth as $5.974 \times 10^{24} \text{ kg}$ and its average radius as 6380 km, calculate the average value of the gravitational field at its surface.
3. Suggest a reason why the vector field lines around a mass are close together near the mass but are further apart at a distance from the mass.
4. Clarify the gravitational field in a region if the field lines are parallel and the same distance apart.
5. The graph shows how the gravitational force on a 400 kg satellite changes with altitude above the planet Mars.
 - (a) Calculate the value of the gravitational field at an altitude of 2400 km.
 - (b) Estimate the gravitational field strength at the surface of Mars.

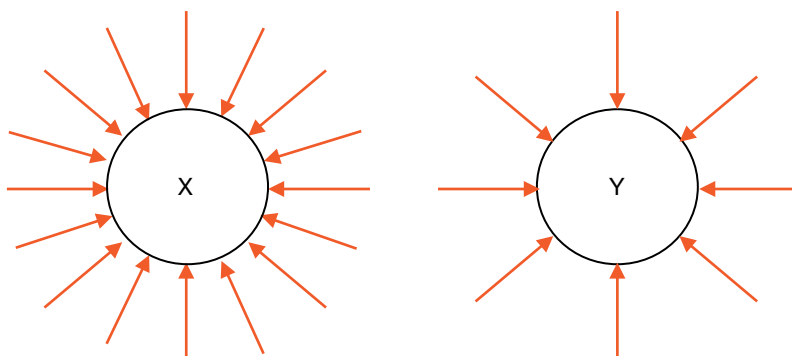


6. In physics, what is a field?
- The immediate space around a charge, mass or magnet.
 - A region in which something experiences a force.
 - The space in which objects are able to move.
 - The region between two charges, masses or magnets.
7. What is a gravitational field?
- The space around a planet.
 - The force holding the planets in orbit around the Sun.
 - The force of attraction between any two masses.
 - The region in which a mass experiences a force.
8. What would be the gravitational field at the midpoint between, and due to two identical planets? Explain your answer.
9. The gravitational field lines are shown for planet X in the diagram.



Planet Y is larger and more massive than planet X. Which statement about a similar diagram for planet Y is correct?

- It would have more field lines.
 - It would have fewer field lines.
 - It would have the same number of field lines.
 - More information is required.
10. The field diagrams shown represent the relative strengths of the gravitational fields of two planets X and Y. The planets have the same radius.



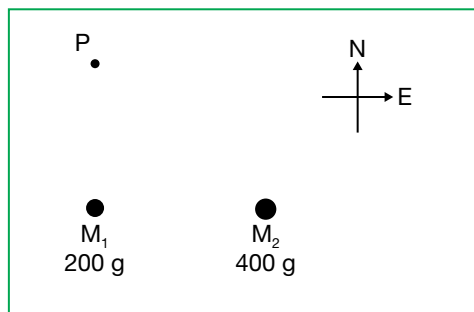
Which statement about these two planets is correct?

- The acceleration due to gravity at the surface of each planet is the same.
 - The mass of planet X must be greater than the mass of planet Y.
 - The gravitational force acting on an object above the surface of X will be less than the gravitational force acting on the same object the same distance above the surface of Y.
 - The gravitational force on an object above the surface of X will be less than the gravitational force on the same object the same distance above the surface of Y.
11. Rewrite the incorrect choices in Question 10 so that they make correct statements.
12. The Earth has a mass about 80 times that of the Moon. Consider the diagram which shows four points in space between the Earth and the Moon. Point F is halfway between them.
- At which point would the gravitational fields due to the Earth and the Moon be closest to equal?

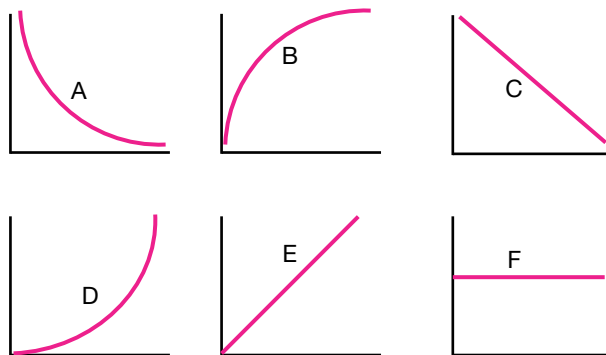


- E
- F
- G
- H

13. A gravitational force of F newtons exists between two objects. What would be the new gravitational force between them if the mass of one object was doubled, and the distance between them was halved?
(A) $0.5F$ (B) $2F$ (C) $4F$ (D) $8F$
14. The gravitational field at point P, distance d from the centre of a planet is $g \text{ m s}^{-2}$. What would be the gravitational field at each of the following points?
(a) Point Q, twice as far from the planet's centre.
(b) Point R half the distance from the planet's centre.
(c) Point S, distance d from the centre of another planet with twice the mass.
(d) Point T, distance d from the centre of another planet with half the mass.
15. An astronaut in a space suit weighs 882 N on Earth. The magnitude of the gravitational field is 9.8 N kg^{-1} .
(a) What would his weight be where the field strength was 2.2 N kg^{-1} ?
(b) What would he weigh where the field strength was 12.2 N kg^{-1} ?
16. Consider two point masses M_1 and M_2 , masses 200 g and 400 g respectively placed 18 cm apart as shown in the diagram.



- (a) Determine the gravitational field strength at point P, 20 cm from M_1 as shown, due only to M_1 .
(b) Determine the gravitational field strength at point P, 27 cm from M_2 as shown, due only to M_2 .
(c) Determine the gravitational field strength at P due to both masses.
17. Compare the gravitational field strength at sea level on Earth with the field strength on top of Mount Everest. Explain your answer.
18. On the surface of Planet X an object has a weight of 63.5 N and a mass of 22.5 kg. What is the gravitational field strength on the surface of Planet X?
19. Consider the graphs below.



Placing gravitational field always on the y-axis, which graph best shows the relationship between gravitational field strength and:

- (a) Distance from a planet's centre.
(b) Mass of the planet.
(c) The mass of the object in the field.
(d) (Inverse of the distance from the planet's centre)².



Answers

1 Newton's Laws of Gravitation

1. 9.77 m s^{-2}
2. 0.332 N if weight on Earth calculated using $w = mg$ ($g = 9.8$). If calculated using Newton's formula, g works out to be 9.796, so difference is 0.03 N.
3. $9.6 \times 10^{-9} \text{ N}$
4. 2.6 times greater.
5. (a) 1.44 m s^{-2}
(b) 0.15 times
(c) 14.4 N
6. 2 : 1
7. (a) Force will be $\frac{1}{4}$ original value.
(b) Force will be 4 times larger.
(c) Force will be doubled.
8. 1 : 1. Gravitational force between X and Y depends only on the mass of X and Y, and the distance between them – this will be the same anywhere in the Universe.
9. (a) 325.7 km
(b) 578.5 N
10. Approximately $3.47 \times 10^5 \text{ km}$ from the centre of Earth. (Hint: Take distance of zero field point as $x \text{ km}$ from Earth and $(385\,000 - x) \text{ km}$ from Moon.
Use $g = \frac{GM_E}{x^2} = \frac{GM_M}{(385\,000 - x)^2}$ and take square roots of both sides before doing the maths).
11. From $W = mg = \frac{mv^2}{r} = \frac{2E_K}{r} = 750 \text{ N}$
12. $8W$
13. 13
14. 11.27 m s^{-2}
15. 5.6 m s^{-2}
16. $1.03 \times 10^{-3} \text{ N}$ towards Jupiter
17. D
18. A
19. B
20. C
21. A
22. C
23. B
24. C

2 Gravitational Field

1.

Factor (position on Earth)	Value of g	Explanation
Sea level, middle of Australia	> 9.8	Thick continental crust underneath with probably higher than average density.
Sea level, on boat in middle of ocean	< 9.8	Deep water underneath and thinner crust means lower than average density.
Sea level at the equator	< 9.8	Largest Earth radius underneath, so g less than average, largest decrease due to rotation of Earth.
Sea level, London	≈ 9.8	Possibly average thickness of crust under, and on edge of continental shelf.
Sea level, North Pole	> 9.8	Smallest radius and zero effect from rotation.
Equator, top of high mountain	< 9.8	Largest radius, greatest effect from rotation, more effect from higher altitude.
Equator, deep down mine shaft	< 9.8	Largest radius, greatest effect from rotation, mine depth insignificant compared to radius.
In plane, flying over ocean	< 9.8	Deep water underneath and thinner crust plus additional effect of higher altitude.
2. 9.789 m s^{-2} (9.8 m s^{-2})
3. The closer we are to a mass, the stronger will be the gravitational field, and since the spacing between the vector lines used to represent gravitational field represents the relative strength of the field, the lines will be closer together closer to the mass.
4. The field will be uniform in strength and in a constant direction.
5. (a) $1.2 \text{ m s}^{-2} (\text{N kg}^{-1})$
(b) 3.75 m s^{-2}
6. B
7. D
8. Zero – Gravitational field is a vector quantity and therefore has direction. A mass placed at this midpoint would experience identical forces in opposite directions (towards each of the planets). The net force on the object would be zero.
9. D (The relative increases in both the mass and radius are required to work out the strength of the gravitational field from $g = \frac{GM}{R^2}$ before an answer can be worked out here.)
10. B

11. (A) The acceleration due to gravity at the surface of *X* is *greater* than that of *Y*.
 (B) *Correct choice.*
 (C) The gravitational force acting on an object above the surface of *X* will be *greater* than the gravitational force acting on the same object the same distance above the surface of *Y*.
 (D) The gravitational potential energy of an object above the surface of *X* will be *greater* than the gravitational potential energy of the same object the same distance above the surface of *Y*.
12. D
 13. D
14. (a) 0.25 g m s^{-2}
 (b) 4 g m s^{-2}
 (c) 2 g m s^{-2}
 (d) 0.5 g m s^{-2}
15. (a) 198 N
 (b) 1098 N
16. (a) $3.34 \times 10^{-10} \text{ m s}^{-2}$ directed away from M_1 through P (bearing 000)
 (b) $3.66 \times 10^{-10} \text{ m s}^{-2}$ directed away from M_2 through P (bearing 318°)
 (c) $6.54 \times 10^{-10} \text{ m s}^{-2}$ bearing 338°
17. The gravitational field on top of Mt Everest will be less than the field on the surface because the top of Mt Everest is further from the centre of the Earth.
18. 2.82 N kg^{-1}
19. (a) A
 (b) E
 (c) F
 (d) E

3 Gravitational Field – Analysing Experiments

1. (a) To examine the relationship between the time it takes an object to fall from various heights and the height from which it is dropped, *and* to use this relationship to calculate a value for the gravitational field.
 (b) Object being dropped, stopwatch used, place where object dropped, air temperature, altitude.
 (c) Height object dropped from.
 (d) Graph should curve gently upwards – will not be straight.
 (e) From graph, about 0.4 s
 (f) 1.05 s
 (g) 11.9 m
 (h) No. Conclusion can only be drawn from a straight line graph. We do not know the equation of the curve, so we cannot specify the relationship. The best that can be said is that as distance fallen increases, time to fall increases, but this is a general statement only, not a conclusion.
- (i) (i), (ii)

Distance object falls (m)	Time to fall (s)	(Time) ² (s ²)
1.0	0.58	0.336
2.0	0.82	0.672
3.0	1.00	1.00
4.0	1.15	1.32
5.0	1.29	1.66
6.0	1.41	1.99
7.0	1.53	2.34
8.0	1.64	2.70

- (iii) Graph will be a straight line.
 (iv) Straight line.
 (v) Time to fall squared is directly proportional to height dropped from.
- (j) 5.95 m s^{-2}
 (k) No, gravity on Earth is 9.8 m s^{-2} or very close to this, depending on altitude.
 (l) Time to fall squared is directly proportional to height dropped from.
 (m) Use average times to fall, repeat with objects of different mass, measure distances several times and use averages.
2. (a) 3000 N
 (b) 306.1 kg
 (c) Not very possible for an average mother (or father!).
 (d) Seatbelt is essential for increased safety.
 (e) Newton's first law of motion (inertia).