SURFING

NATIONAL PHYSICS

Unit 3 Gravity and Electromagnetism

• Brian Shadwick •

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Science Press
Unit 7, 23-31 Bowden Street
Alexandria NSW 2015 Australia
Tel: +61 2 9020 1840 Fax: +61 2 9020 1842
sales@sciencepress.com.au
www.sciencepress.com.au

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Contents

Introduction

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.

Gravity and Motion

1 Mass and Weight

We often use the terms 'mass' and 'weight' – the latter often incorrectly. You do not, for example, 'weigh' 60 kg. Your 'mass' may certainly be 60 kg, but if that is the case, then your 'weight' is closer to 600 N! The difference lies in the following definitions.

Mass is a measure of the amount of matter in an object. Mass does not change, regardless of the position of the object in the Universe. Mass is measured in kilograms (kg) (or mg, g, tonnes etc).

The **weight** of an object is a measure of the force with which it is attracted by a gravitational force. The weight of an object changes depending on where it is in the Universe. Because weight is a force, it is measured in newtons (N).

Mass and weight are connected by the following equation.

$$W_F = mg$$

Weight = mass × acceleration due to gravity

Where W_F = weight in N

m = mass in kg

g = acceleration due to gravity

= 9.8 m s^{-2} (average value on Earth's surface at sea level)

QUESTIONS

1. Contrast mass and weight and give the units used to measure each.
2. Recall the equation connecting mass and weight.
3. Convert to weight: 100 grams, 2.5 kg, 20 kg, 1000 kg.
4. Convert to mass: 10 N, 100 N, 500 N, 10 000 N.
5. (a) Calculate the mass of an 85 kg person on the Moon. (Moon's gravity is about 1.6 m s^{-2}.)
   (b) Calculate this person's weight on the Moon.
   (c) Predict his weight on Earth.
   (d) Calculate the weight of a 55 kg astronaut on Earth.
   (e) Calculate the astronaut's mass and weight on the Moon.

6. The table shows the strength of gravity on heavenly objects compared to Earth.

Heavenly object	Gravitational field compared to Earth = 1
Earth	1.00
Mercury	0.41
Venus	0.91
Mars	0.38
Jupiter	2.53
Saturn	1.07
Uranus	0.88
Neptune	1.16
Pluto	0.064
Sun	28.1

   (a) Calculate the mass of a 1 kilogram block on each heavenly object.
   (b) Calculate its weight on each object.
   (c) Account for the mass and weight difference for each object.
   (d) List reasons for the difference in the force of gravity on each heavenly object.

2 Acceleration Due to Gravity – An Experiment

QUESTIONS

The information in the table was obtained from an experiment where the time it took an object to fall from different heights was measured. Use the information to answer the questions.

Distance fallen (m)	Time to fall (s)
1.0	0.58
2.0	0.82
3.0	1.00
4.0	1.15
5.0	1.29
6.0	1.41
7.0	1.53
8.0	1.64

1. Suggest a purpose of this experiment.
2. Identify factors which would have been controlled.
3. Identify the factors that varied.
4. Graph the information (put t on the x-axis).
5. Predict the time to fall 0.5 m.
6. Predict the time to fall 3.25 m.
7. If it took 2.00 seconds to hit the ground, predict the height it fell from.
8. Can you write a conclusion from this graph? Explain.
9. (a) Copy the table into your book and add a third column headed (Time)^2.
   (b) Calculate values for (Time)^2 and complete your table.
   (c) Graph distance fallen against (Time)^2 (t^2 on x-axis).
   (d) What shape graph do you get?
   (e) What does this tell you?
10. Given that twice the gradient of your graph is equal to the acceleration of the falling object, calculate this acceleration.
11. Is this object falling on Earth? Explain.
12. Write a conclusion for the experiment.
13. Suggest at least one way this experiment could be improved.

Extension

14. The typical acceleration involved when a car, moving at 60 km h^{-1}, crashes into a wall, a pole, or another car is about 150 m s^{-2}. Imagine a mother nursing a 20 kg child in the front seat with no seatbelt holding the child.
    (a) Calculate the force needed on the child to resist the deceleration of the car.
    (b) If the mother applied this force to weightlifting weights, calculate how much she would lift.
    (c) How possible is this?
    (d) What implications does this have for nursing an unbelted child in a car?
    (e) Identify the law involved in this example.

Additional analysis

15. The table shows the results of a similar experiment done on the planet Xenos.

Height object dropped from (m)	Time to fall (s)
1.0	0.63
1.5	T
2.0	0.89
P	1.00
3.0	U
Q	1.26
R	1.34
5.0	1.41
S	1.67
8.0	V
10.0	2.0

    (a) Analyse these results to calculate the acceleration due to gravity on Xenos.
    (b) Using this, or by any other means, deduce values for the missing quantities in the table.
    (c) Calculate the mass and weight of an 80 kg astronaut on Xenos.

3 Acceleration Due to Gravity – Another Experiment

QUESTIONS

The information in the table was obtained from an experiment. Use the information to answer the questions that follow.

Length of pendulum string (m)	Average time for 1 complete swing (s)
0.5	1.41
1.0	2.00
1.5	2.45
2.0	2.83
2.5	3.16
3.0	3.46
3.5	3.74
4.0	4.00

1. Draw a diagram to show how the experiment might have been done.
2. Identify the purpose of this experiment.
3. What are these results telling us?
4. Identify factors that would have been controlled in this experiment.
5. Identify the factors that have been varied.
6. Graph the results.
7. Predict the pendulum length for a one second swing.
8. What does the graph tell us?
9. Copy the results table into your book, adding a third column to it. Put the heading (Time for one swing)^2. Square each time value and complete your third column.
10. Draw a graph to show the relationship between the length of the pendulum and (Time for one swing)^2.
11. Deduce the length of the pendulum if the time for one complete swing was 1.00 seconds according to this graph.
12. Explain any difference in your answers to Questions 7 and 11.
13. What is this graph telling us?
14. What special name do we give for 'one complete swing' of a pendulum?
15. What name do we give to motion which is back and forth like a pendulum swinging?
16. Write a conclusion for the experiment.
17. Use the results of the experiment and the formula below to find a value for the acceleration due to gravity.

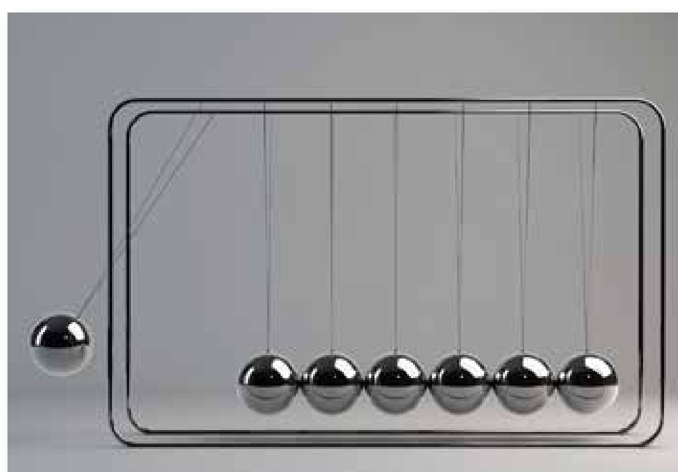
$$T = 2\pi\sqrt{\frac{l}{g}}$$

A Xenos swinging time

A pendulum experiment was done on the planet Xenos to determine its gravity. The results are shown in the table.

Run	Length of pendulum (m)	Time for 20 swings (s)
1	0.1	15.6
2	0.2	22.1
3	0.3	27.0
4	0.4	31.2
5	0.5	34.9
6	0.1	15.5
7	0.1	15.6
8	0.1	15.7

1. Use the results to calculate the average values for the acceleration due to gravity on Xenos.
2. The experiment was repeated using a mass on the end of the pendulum string (the 'bob') three times larger. Predict how this would change the results and justify your answer.
3. Predict the time for 20 swings of a 1.0 m long pendulum on Xenos.
4. Contrast the time for 20 swings on Xenos and a small moon of Xenos. Justify your answer.
5. Contrast the time for 20 swings on moon X, which is twice as massive as moon Y, but with the same radius. Justify your answer.



4 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.

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

G = the **universal gravitational constant**
= 6.67×10^{-11} N m^2 kg^{-2}
r = the distance between the centres of the two (distance apart plus radii)
$m_{1/2}$ = 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: $F_g = \frac{Gm_1M_{Earth}}{r^2} = m_1g$

r = radius of Earth plus height object is above the surface (average radius = 6.378×10^6 m)

Gravitational acceleration on other planets or moons

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

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

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.

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

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: $g_{\text{Earth}} = \frac{GM_{\text{Earth}}}{\left(r_{\text{Earth}}\right)^2}$ and $g_{\text{planet}} = \frac{GM_{\text{planet}}}{\left(r_{\text{planet}}\right)^2}$

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

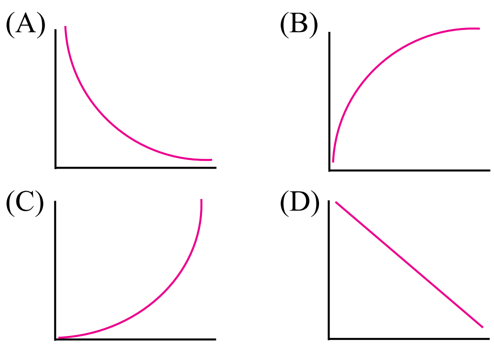
QUESTIONS

1. 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.
2. You have a mass of 60 kg. Predict your 'loss' in weight at the top of Sydney Tower, 305 m above sea level.
3. Calculate the gravitational force between you and another person (both mass 60 kg), 5 m apart.
4. 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.
5. The mass of Ganymede is 1.5×10^{23} kg and its diameter is about 5270 km.
   (a) Calculate the acceleration due to gravity on the surface of Ganymede.
   (b) How does this compare with Earth's gravity?
   (c) Calculate the weight of a 10 kg mass on Ganymede's surface.
6. Two moons have masses M and $2M$ and radii R and $2R$ respectively. Compare their accelerations due to gravity.
7. Predict the effect on the gravitational force between two objects of:
   (a) Doubling the distance between them.
   (b) Doubling both masses.
   (c) Halving one mass and the distance between them.
8. Compare the gravitational force of attraction between masses X and Y, 10 kg and 20 kg respectively, 5 m apart, on the Moon ($g = 1.6$ m s^{-2}) and on Earth.
9. 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.
   (a) What is the altitude of the shuttle?
   (b) What is the weight of a 65 kg astronaut in this shuttle?
10. 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.
11. 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?
12. 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?
13. 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?
14. 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?
15. An object weighs 147 N on Earth and 84 N on planet X. What is the acceleration due to gravity on planet X?
16. 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.

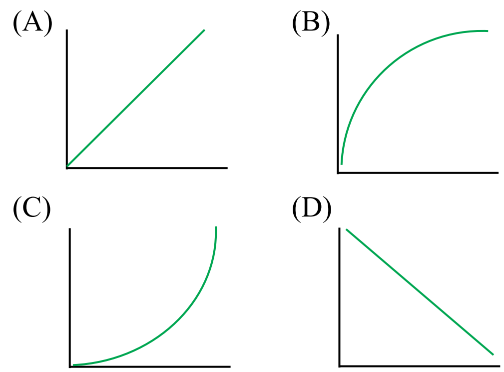
18. Which graph best shows the relationship between gravitational force and distance from the centre of a planet?



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

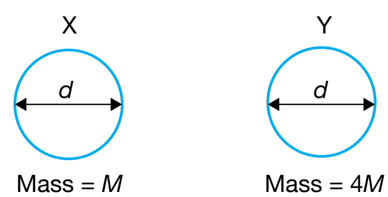
21. Which graph best shows the relationship between gravitational force and the mass of a planet?



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.



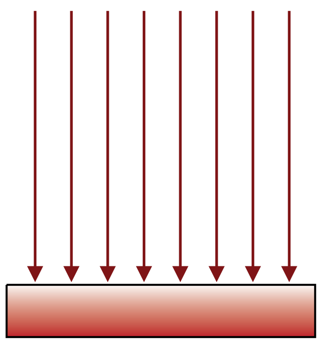
The gravitational force on X due to Y is F. What is the gravitational force on Y due to X?
(A) $0.25F$ (B) $0.5F$ (C) F (D) $4.0F$

5 Gravitational Field

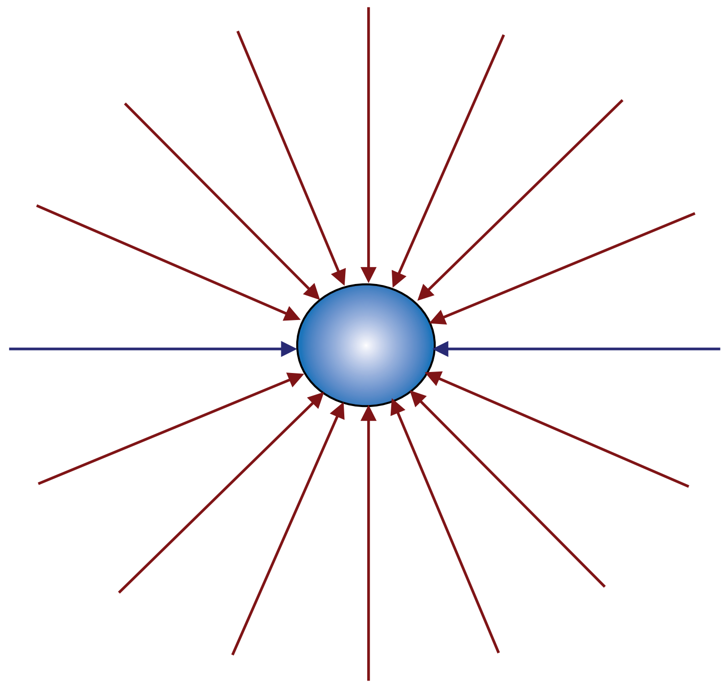
A **field** is a region in which something experiences a force. A mass experiences a force in a gravitational field, directed downwards, towards the centre of the Earth.

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.



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



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

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.

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.

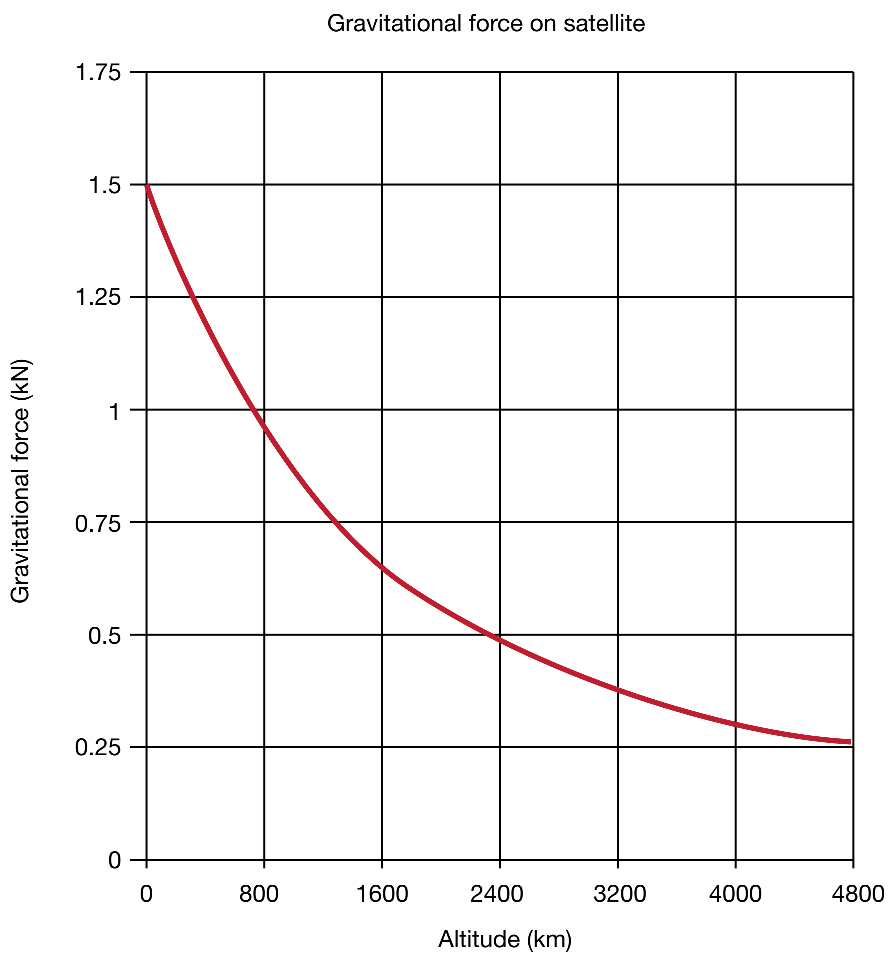
- The Earth's crust varies in structure, thickness and density. Crust under oceans is thinner than continental crust. Continental crust is thickest under mountains. Density changes due to the presence of minerals, oil or gas trapped in rock structures. These variations influence local values of g.
- 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. Complete the table 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 5.974×10^{24} kg and its average radius as 6380 km, calculate the average value of the gravitational field at its surface.
3. 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.
4. Explain why the field lines around a mass are close together near the mass but are further apart at a distance from the mass.



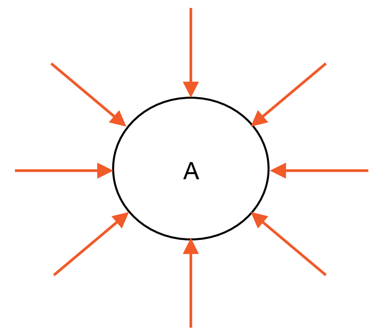
5. Clarify the gravitational field in a region if the field lines are parallel and the same distance apart.

6. In physics, what is a field?
(A) The immediate space around a charge, mass or magnet.
(B) A region in which something experiences a force.
(C) The space in which objects are able to move.
(D) The region between two charges, masses or magnets.

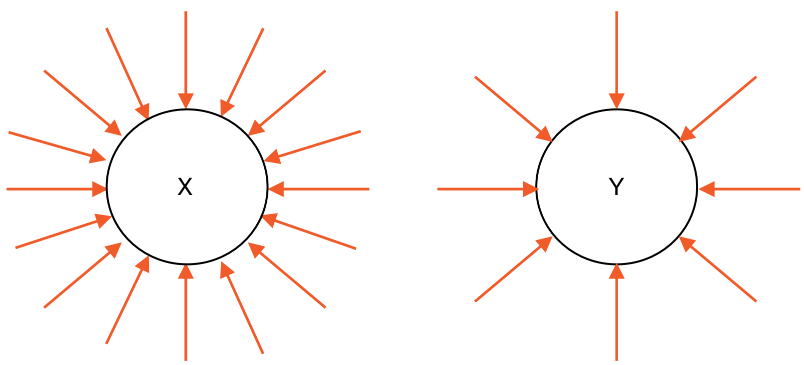
7. What is a gravitational field?
(A) The space around a planet.
(B) The force holding the planets in orbit around the Sun.
(C) The force of attraction between any two masses.
(D) The region in which a mass experiences a force.

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 A in the diagram.
Planet B is larger and more massive than planet A.
Which statement about a similar diagram for planet B is correct?
(A) It would have more field lines.
(B) It would have fewer field lines.
(C) It would have the same number of field lines.
(D) More information is required.



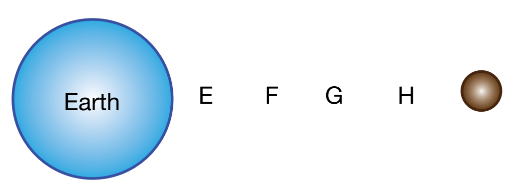
10. The field diagrams shown represent the relative strengths of the gravitational fields of two planets X and Y. The planets have the same radius.



(a) Which statement about these two planets is correct?
(A) The acceleration due to gravity at the surface of each planet is the same.
(B) The mass of planet X must be greater than the mass of planet Y.
(C) 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.
(D) 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.

(b) Rewrite the incorrect choices so that they make correct statements.

11. 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?
(A) E
(B) F
(C) G
(D) H



12. 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) $8F$

13. The gravitational field at point P, distance d from the centre of a planet is g m s^{-2}. What would be the gravitational field at each of the following points?

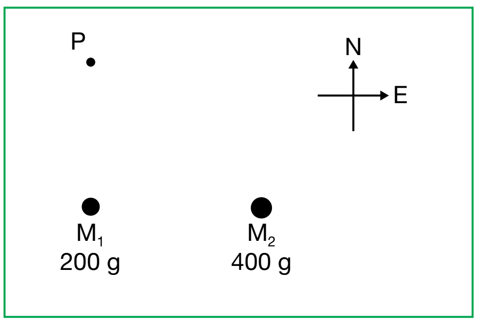
(a) Point Q, twice as far from the planet's centre.

(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.

14. 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.

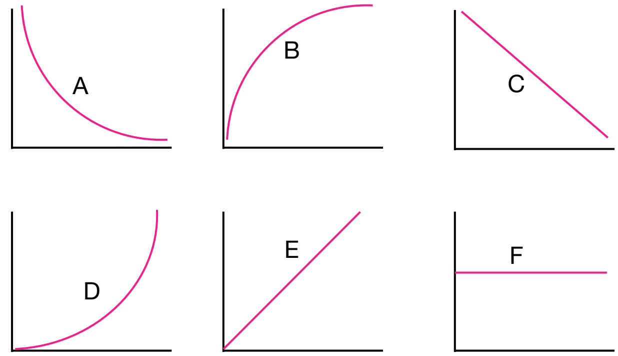


(a) Determine the gravitational field strength at point P, 20 cm from M_1 as shown, due only to M_1.

(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.

15. Consider the graphs below.



Placing gravitational field always on the y-axis, find 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 Mass and Weight

1. Mass is a measure of the amount of matter in an object. Weight is a measure of the attraction of gravity on a mass. Mass = kg, weight = N.
2. $W = mg$
3. 100 grams = 0.98 N
   2.5 kg = 24.5 N
   20 kg = 196 N
   1000 kg = 9800 N
4. 10 N = 1.02 kg
   100 N = 10.2 kg
   500 N = 51 kg
   10 000 N = 1020.4 kg
5. (a) 85 kg
   (b) 136 N
   (c) 833 N
   (d) 539 N
   (e) 55 kg, 88 N
6. (a) 1 kg – mass does not change.
   (b) Mercury = 4.02 N
   Venus = 8.92 N
   Earth = 9.8 N
   Mars = 3.72 N
   Jupiter = 24.8 N
   Saturn = 10.5 N
   Uranus = 8.6 N
   Neptune = 11.4 N
   Pluto = 0.63 N
   Sun = 275.38 N
   (c) Weight depends on the strength of the gravitational field on the mass – this varies for each heavenly object.
   (d) Different masses and radii of each heavenly object.

2 Acceleration Due to Gravity – An Experiment

1. 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 acceleration due to gravity.
2. Object being dropped, stopwatch used, place where object dropped, air temperature, altitude.
3. Height object dropped from.
4. Graph should curve gently upwards – it will not be straight.
5. From graph, about 0.4 s.
6. 1.05 s
7. 11.9 m
8. 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.
9. (a) and (b)

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

   (c) Graph will be a straight line.
   (d) Straight line.
   (e) Time to fall squared is directly proportional to height dropped from.
10. 5.95 m s^{-2}
11. No, gravity on Earth is 9.8 m s^{-2} or very close to this, depending on altitude.
12. Time to fall squared is directly proportional to height dropped from.
13. Use average times to fall, repeat with objects of different mass, measure distances several times and use averages.