SPACE

Mind map

CHAPTER 1

Gravity

The Earth has a gravitational field that exerts a force on objects both on it and around it

Introduction

In March 1906, the first (mono)plane was constructed and flew a distance of 12 m. On October 4, 1957, the Soviet Union launched the world's first artificial satellite, *Sputnik 1*. On January 31, 1958, the first US satellite, *Explorer 1*, was launched. On July 20, 1969, *Apollo 11* landed two men on the surface of the Moon for the first time. On April 12, 1981, the first reusable manned vehicle, the *Space Transportation System* (colloquially known as the space shuttle) was launched by the United States. Humans have come a long way in developing technologies and improving instruments for space travel and exploration.

Chapter 1 looks at the behaviours and interactions of objects in the Universe under the influence of gravity. The concepts of gravitational acceleration and potential energy will be discussed in detail.

1.1 Gravitational field and weight

■ *Define weight as the force on an object due to a gravitational field*

Any object with mass has its own gravitational field. The analogy is that a stationary electrical charge produces an electrical field and a bar magnet produces a magnetic field. So it is that a 'mass' produces a gravitational field.

What is the difference between 'mass' and 'weight'?

Definition

Mass is the quantity of matter; it is an absolute measurement of how much matter is in a body or an object. Mass has the SI unit of kilogram (kg).

Definition

Weight is the force which acts on a mass within a gravitational field. Weight is proportional to the strength of the gravitational field. The SI unit for weight is the **newton (N)**.

Mass and weight can be related by a simple equation:

$$F = mg$$

Where:

F = weight or the weight force (usually used interchangeably), measured in N

m = mass of the object, measured in kg

g = gravitational acceleration on the object due the presence of the gravitational field, measured in m s^{-2}

For example, an object with a mass of 5 kg will have different weights on different planets such as Earth, Jupiter or Saturn, due to the different gravitational field strengths or gravitational accelerations.

NOTE: In everyday life, 'weight' can actually refer to 'mass'. For instance: 'How much do you weigh?' '70 kg', might be the answer. Clearly, the unit is in kg, not N. Bathroom scales actually measure the weight force and automatically convert the read-out into the mass equivalent, assuming the scales are on Earth.

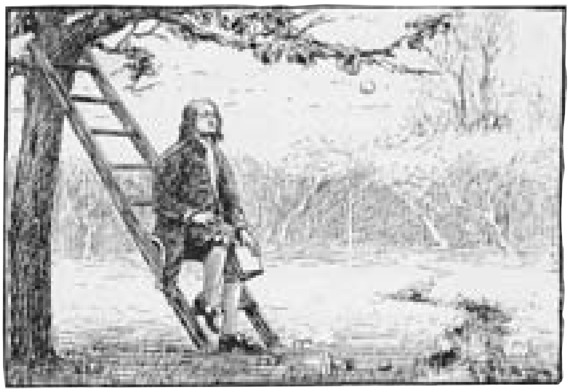
NOTE: On Earth's surface, g can be taken as 9.8 m s^{-2} downwards.

Universal gravitation

1.2

For only two masses separated in space, there is a force of attraction between them due to the interaction of their gravitational fields. This is what Sir Isaac Newton referred to as the **law of universal gravitational attraction**. The attraction force is acting towards the centre of each mass.

The magnitude of the attraction force between two objects is proportional to the product of their masses and inversely proportional to the square of the distance of their separation:



Observing an apple falling inspired Sir Isaac Newton to develop the law of universal gravitational attraction

$$F = G\frac{m_1 m_2}{d^2}$$

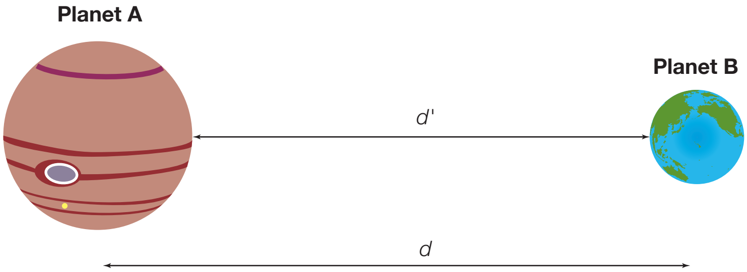
Where:

m_1 and m_2 = masses of the two objects, measured in kg

d = the distance between the two objects measured from the centre of each object (**mass**) as shown in Figure 1.1; the distance is measured in m

G = the universal gravitational constant, that is, 6.67×10^{-11} N m^2 kg^{-2}

Figure 1.1 The distance ***d*** is measured from the centres of the masses, so the distance in this case is ***d*** not ***d***[1]



NOTE: A common error is to leave out the square sign on $\boldsymbol{d}^2$. There is a justification for this square sign: the gravitational field radiates out three-dimensionally, just as light radiates out from a candle. Light intensity follows the **inverse square law**, where the intensity is inversely proportional to the distance squared.

$$I \propto \frac{1}{\boldsymbol{d}^2}$$

$$\therefore I = k\frac{1}{\boldsymbol{d}^2}$$

The gravitational field strength also follows the inverse square law, so the field strength is inversely proportional to the distance squared. Consequently, the attraction force is also inversely proportional to the distance squared.

Example 1

Why don't two people walking on the street get pulled towards each other due to a mutual gravitational attraction?

Solution

Consider the following: two people, one weighing 60 kg and the other weighing 80 kg, are separated by a distance of 5.0 m on the street. Calculate the attraction force between them.

$$\boldsymbol{F} = G\frac{m_1 m_2}{\boldsymbol{d}^2}$$

Known quantities:

$$G = 6.67 \times 10^{-11}$$
$$m_1 = 60 \text{ kg}$$
$$m_2 = 80 \text{ kg}$$
$$\boldsymbol{d} = 5.0 \text{ m}$$
$$\therefore \boldsymbol{F} = \frac{6.67 \times 10^{-11} \times 60 \times 80}{5.0^2}$$
$$= 1.3 \times 10^{-8} \text{ N Towards each other}$$

The force between them is too small to have any effect, in fact, it is even too small to be detected in any usual manner.

Example 2

Determine the magnitude of the gravitational attraction force between the Sun and the Earth, given that the mass of the Sun is 1.99×10^{30} kg, the mass of the Earth is 6.0×10^{24} kg and they are separated by 1.5×10^{8} km as measured between their centres.

Solution

$$\boldsymbol{F} = G\frac{m_1 m_2}{\boldsymbol{d}^2}$$

$$m_1 = 1.99 \times 10^{30} \text{ kg}$$
$$m_2 = 6.0 \times 10^{24} \text{ kg}$$
$$G = 6.67 \times 10^{-11}$$
$$\boldsymbol{d} = 1.5 \times 10^{11} \text{ m}$$
$$\therefore \boldsymbol{F} = \frac{(6.67 \times 10^{-11})(1.99 \times 10^{30})(6.0 \times 10^{24})}{(1.5 \times 10^{11})^2}$$
$$= 3.54 \times 10^{22} \text{ N Attraction}$$

1.3 A closer look at gravitational acceleration

'$\boldsymbol{g}$' is the gravitational acceleration acting on an object due the presence of the gravitational field. What are the factors that determine the magnitude of $\boldsymbol{g}$?

Consider an object on the surface of the Earth which has a mass of M, as shown in Figure 1.2. The object with mass m will have a weight force of $\boldsymbol{F}_w = m\boldsymbol{g}$ towards the centre of the Earth. This weight force is created by the universal gravitation attraction force between the object and the Earth.

$$\boldsymbol{F}_g = \boldsymbol{F}_w$$
$$\boldsymbol{F}_g = G\frac{mM}{\boldsymbol{d}^2}$$
$$\boldsymbol{F}_w = m\boldsymbol{g}$$
$$G\frac{mM}{\boldsymbol{d}^2} = m\boldsymbol{g}$$
$$\therefore \boldsymbol{g} = G\frac{M}{\boldsymbol{d}^2}$$

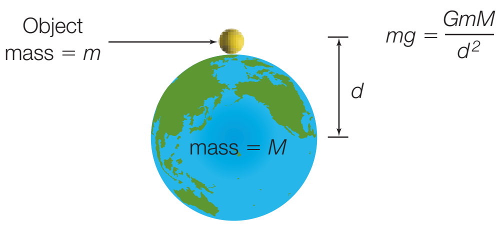


Figure 1.2 An object on the surface of the Earth

$$\boldsymbol{g} = G\frac{M}{\boldsymbol{d}^2}$$

To summarise, the gravitational acceleration of any planet is proportional to the mass of the planet and inversely proportional to the square of the distance from the centre of the planet.

This equation can be generalised for any planet.

Where:

M = the mass of the planet, such as the Earth, measured in kg

d = the distance from the centre of the planet to the point at which $\boldsymbol{g}$ is measured. The distance is measured in metres. If the object is at the planet's surface, then $\boldsymbol{d} = r$, where r is the radius of the planet.

SECONDARY SOURCE INVESTIGATION

PHYSICS SKILLS

H14.1A, D, E, G, H
H14.2A
H14.3C, D

g on other planets and the application of $F = mg$

- ***Gather secondary information to predict the value of acceleration due to gravity on other planets***
- ***Analyse information using the expression $F = mg$ to determine the weight force for a body on Earth and for the same body on other planets***

The value of the gravitational acceleration, $\boldsymbol{g}$, on the surface of any planet or other body can be found by using its radius and its mass. Once $\boldsymbol{g}$ is known, the weight of any object can be calculated.

Example 1

Find the value of the gravitational acceleration on the surface of the Earth.

$$\boldsymbol{g} = G\frac{M}{\boldsymbol{d}^2}$$

Mass of the Earth: 6.0×10^{24} kg
Radius of the Earth: 6.37×10^3 km

$$\boldsymbol{g} = \frac{(6.67 \times 10^{-11})(6.0 \times 10^{24})}{(6.37 \times 10^6)^2}$$

$= 9.84$ m s^{-2} downward

NOTE: Remember to convert the radius in kilometres to metres, as the $\boldsymbol{d}$ in the formula is *only* measured in metres.

Example 2

Find the magnitude of the gravitational aceleration on the surface of the planet Jupiter.

$$\boldsymbol{g} = G\frac{M}{\boldsymbol{d}^2}$$

Mass of Jupiter: 1.90×10^{27} kg
Radius of Jupiter: 7.15×10^4 km

$$\boldsymbol{g} = \frac{(6.67 \times 10^{-11})(1.90 \times 10^{27})}{(7.15 \times 10^7)^2}$$

$= 24.8$ m s^{-2} towards the centre of Jupiter

Example 3

Calculate the weight of a textbook with a mass of 5.0 kg on both Earth and Jupiter.

$$\boldsymbol{F} = mg$$

(a) On Earth: $\boldsymbol{g}$ = 9.84 m s^{-2}

$$\boldsymbol{F} = 5.0 \times 9.84$$
$$= 49.2 \text{ N}$$

(b) On Jupiter: $\boldsymbol{g}$ = 24.80 m s^{-2}

$$\boldsymbol{F} = 5.0 \times 24.8$$
$$= 124 \text{ N}$$

NOTE: This example again shows that the mass of an object is an absolute quantity, whereas the weight changes with variations in gravitational acceleration.

Table 1.1 provides information about the **mass** and radius of the planets and Pluto, the Sun and the Earth's Moon and the values of their gravitational acceleration, as well as the weight of an object with a mass of 5.0 kg on their surface.

Table 1.1

	Mass (kg)	Radius (km)	Surface gravity m s^{-2}	Weight of an object with a mass of 5.0 kg (N)
Earth	6.0×10^{24}	6378	9.84	49.19
Mercury	3.30×10^{23}	2439	3.70	18.50
Venus	4.87×10^{24}	6051	8.88	44.40
Mars	6.42×10^{23}	3393	3.62	18.10
Jupiter	1.90×10^{27}	71492	24.81	124.05
Saturn	5.69×10^{26}	60268	10.45	52.25
Uranus	8.68×10^{25}	25559	8.87	44.35
Neptune	1.02×10^{26}	24764	11.10	55.50
Pluto	1.29×10^{22}	1150	0.65	3.25
Moon	7.35×10^{22}	1738	1.62	8.10
Sun	1.99×10^{30}	696000	274.13	1370.65

Variation in the Earth's gravitational acceleration

Earth's gravitational acceleration $\boldsymbol{g}$ has so far been treated as a constant, with a value of 9.8 m s^{-2}. However, the value for $\boldsymbol{g}$ varies depending on a number of factors.

Factors that can affect the value of $\boldsymbol{g}$ are:

- altitude
- local crust density
- the rotation of the Earth
- the shape of the Earth (which is not a perfect sphere)

Altitude

Example

Find the values of $\boldsymbol{g}$ when measured at:

(a) The top of a building with a height of 100 m.
(b) The summit of Mount Everest with a height of 8848 m.
(c) The altitude of a low earth orbit satellite, which is 310 km.

$$\boldsymbol{g} = G\frac{M}{\boldsymbol{d}^2}$$

Known quantities:

$G = 6.67 \times 10^{-11}$

$M = 6.0 \times 10^{24}$ kg

(a) $\boldsymbol{d}$ = 6378000 m + 100 m = 6378100 m

$$\boldsymbol{g} = \frac{(6.67 \times 10^{-11})(6.0 \times 10^{24})}{(6378100)^2}$$

$\boldsymbol{g}$ = 9.84 m s^{-2} towards the centre of the Earth

(b) $\boldsymbol{d}$ = 6378000 m + 8848 m = 6386848 m

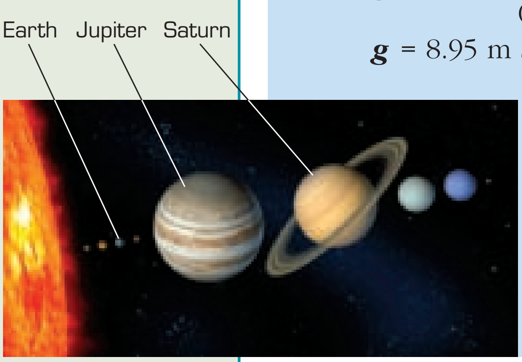
$$\boldsymbol{g} = \frac{(6.67 \times 10^{-11})(6.0 \times 10^{24})}{(6386848)^2}$$

$\boldsymbol{g}$ = 9.81 m s^{-2} towards the centre of the Earth

(c) $\boldsymbol{d}$ = 6378000 m + 310000 m = 6688000 m

$$\boldsymbol{g} = \frac{(6.67 \times 10^{-11})(6.0 \times 10^{24})}{(6688000)^2}$$

$\boldsymbol{g}$ = 8.95 m s^{-2} towards the centre of the Earth



Saturn and Jupiter have radii much larger than Earth's

These examples show that the value of $\boldsymbol{g}$ changes with the altitude at which it is measured. The further away you are from the centre of the Earth, the smaller $\boldsymbol{g}$ is. However, the change only becomes significant at very high altitudes. Even at the summit of Mount Everest, $\boldsymbol{g}$ only decreases by about 0.3%, which would not be noticed by people climbing the summit.

Local crust density

The Earth's crust does not have uniform density. Some areas have a greater density (for example where there are dense mineral deposits); by volume these areas will have a greater mass. Since the gravitational field strength is affected by mass, areas with greater density tend to have slightly bigger $\boldsymbol{g}$ values. (Such variations are used in the mining industry to detect the location of mineral deposits or, if the value of $\boldsymbol{g}$ is lower than normal, to detect the presence of natural gas or oil reserves.)

The rotation of the Earth

As the Earth rotates once every 24 hours, any place on the equator is moving towards the east at about 1670 km h^{-1} relative to the North or South Pole. Just like on an imaginary fun ride, the effect is to try to 'fling' objects off the surface of the Earth. Such an effect is not normally noticed. (The Earth would need to rotate once every 20 seconds in order to actually fling an object off its surface at the equator!) However, this does reduce the **g** value slightly.

The shape of the Earth

Due to its rotation, the Earth bulges slightly at the equator, resulting in the overall shape being slightly flattened at the poles. (This shape is known as an ellipsoid.) A person standing on the North or South Pole (at sea level) is closer to Earth's centre than a person standing on the equator by about 10 km. This explains why at the equator, the $\boldsymbol{g}$ value is slightly smaller than the value at the poles.

1.4 Gravitational potential energy

- ***Explain that a change in gravitational potential energy is related to work done***
- ***Define gravitational potential energy as the work done to move an object from a very large distance away to a point in a gravitational field***

$$E_p = -G\frac{m_1 m_2}{r}$$

A waterfall demonstrates the concept of gravitational potential energy

Gravitational potential energy, E_p, is the energy stored in a body due to its position in a gravitational field. This energy can be released (and converted into kinetic energy) when the body is allowed to fall.

The work done, W, on an object when a force acting on the object causes it to move is given by:

$W = \boldsymbol{F} \times \boldsymbol{s}$, where $\boldsymbol{F}$ is the force acting, and $\boldsymbol{s}$ is the distance the object is moved while the force is acting as shown in Figure 1.3(a).

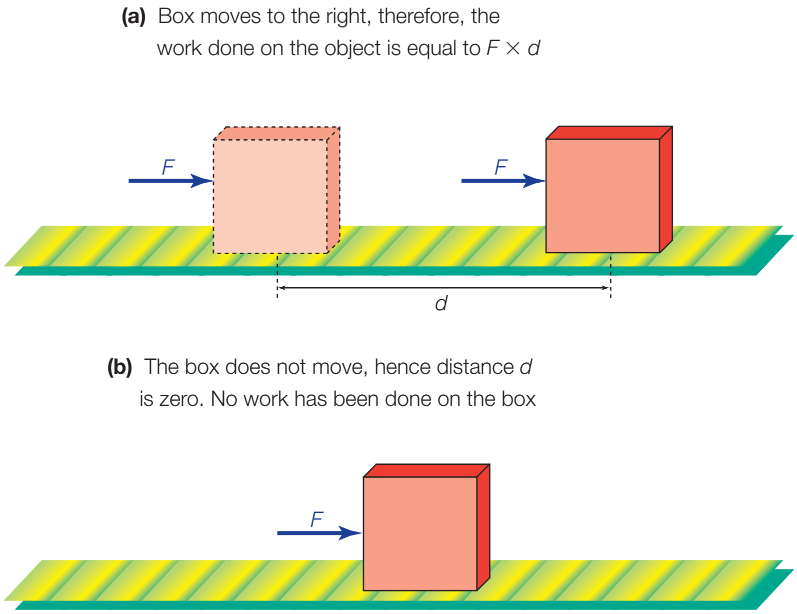


Figure 1.3 Work

SR

Worked examples 1, 2

A similar idea is used when an object is lifted to a height above the ground. Because the force is now working against gravity, the force required to lift the object must be equal (strictly speaking just greater than) the weight force of the object (mg). The work done is stored in the object if it remains at that position. Hence the work done on the object is equivalent to its gain in gravitational potential energy. Lifting this book (mass approximately 1 kg) to a height of 1 metre above the desk requires about 9.8 joules (J) of work to be done. This work done is now stored as gravitational potential energy and is released if the book is now dropped and allowed to fall back to the desk, being transformed into kinetic energy and then sound.

When an object is raised to a height $\boldsymbol{h}$ above the ground, then its gravitational potential energy becomes:

$E_p = W = \boldsymbol{F} \times \boldsymbol{s}$

$\boldsymbol{F} = mg$ (as the force needed must be at least equal to the weight force of the object)

$\boldsymbol{s} = \boldsymbol{h}$ (as the height is the distance moved)

$E_p = mgh$

$$E_p = mgh$$

Where:

E_p = gravitational potential energy, measured in J

m = mass of the object, measured in kg

$\boldsymbol{g}$ = gravitational acceleration, measured in m s^{-2}

$\boldsymbol{h}$ = height above the ground, measured in m

Problem! This equation is quite accurate when the object is near the surface of the Earth. However it assumes that the value of $\boldsymbol{g}$ is a constant and does not change with altitude (it does change), and cannot be used to determine an absolute value for the amount of gravitational energy posssessed by an object. It implies that any arbitrary place can be used as the reference position where the object has no gravitational potential energy (e.g. the floor, desktop, the Earth's surface).

A universal definition of gravitational potential energy is required.

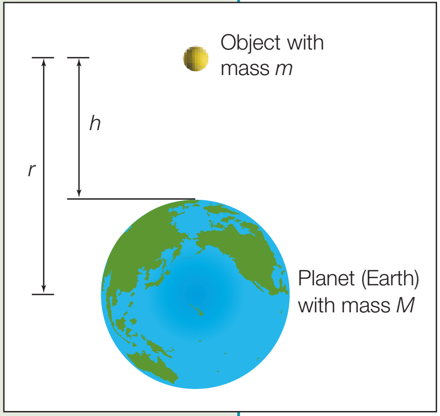


Figure 1.4 Earth and a distant object

$E_p = m\boldsymbol{g}h$

$\boldsymbol{g} = G\dfrac{M}{r^2}$

$r = h$ + Earth's radius, since $\boldsymbol{g} = G\dfrac{M}{r^2}$ is measured with reference to the Earth's centre

$E_p = G\dfrac{mM}{r^2} \times r$

$E_p = G\dfrac{mM}{r}$

NOTE: In this case, E_p is measured from the centre of the Earth. This is because the distance r is taken from the centre of the Earth.

$$E_p = -G\frac{mM}{r}$$

Where:

E_p = gravitational potential energy, measured in J

m = mass of the object, measured in kg

M = mass of the planet, measured in kg

G = universal gravitational constant, which is equal to 6.67×10^{-11} N m^2 kg^{-2}

r = height at which the E_p is measured, as measured from the centre of the planet, measured in m

NOTE: If E_p is measured at the surface of the planet, then r is the radius of the planet.

Example 1

Calculate the gravitational potential energy of a satellite with mass 110 kg, at an altitude of 320 km above the Earth.

$$E_p = -G\frac{mM}{r}$$

$G = 6.67 \times 10^{-11}$

$m = 110$ kg

$M = 6.0 \times 10^{24}$ kg

$r = 6378000 \text{ m} + 320000 \text{ m} = 6698000 \text{ m}$

$$E_p = -\frac{(6.67 \times 10^{-11}) \times (110) \times (6.0 \times 10^{24})}{6698000}$$

$E_p = -6.57 \times 10^9$ J

Or

$= -6572$ MJ

Why is the gravitational potential energy negative?

At a position very far away from Earth, an object would experience negligible gravitational attraction. The place at which gravity becomes zero is in fact an infinite distance away. By definition, any object at such a distance is said to have zero gravitational potential energy. If an object was then given a small ‘nudge’ or a push towards Earth, it would begin to fall towards Earth, losing gravitational potential energy as it gains kinetic energy. The more gravitational potential energy the object loses, the more negative the value of E_p (subtracting from zero results in a negative value).

Conversely, to reach this infinite distance from within the gravitational field, positive work has to be done on the object, that is, effort is required to push the object upwards. So, if positive work is added to the object and the object ends up with a zero gravitational potential energy at an infinite point from the Earth, the object at anywhere below that point must have a negative energy.

ANALOGY: If you keep adding positive numbers to an unknown number, and end up with a zero, then you are quite certain that you started off with a negative number.

Change in gravitational potential energy (ΔE_p)

Although the gravitational potential energy is negative, the *change* in gravitational potential energy can be positive. The change in gravitational potential energy is equal to the second potential energy minus the first potential energy, or more correctly it is the less negative potential energy minus the more negative potential energy.

For two positions in the gravitational field with distances of $\boldsymbol{r}_1$ and $\boldsymbol{r}_2$ from the centre of the Earth respectively, where $\boldsymbol{r}_1$ is greater than $\boldsymbol{r}_2$:

$$\Delta E_p = -G\frac{mM}{r_1} - \left(-G\frac{mM}{r_2}\right)$$

$$= G\frac{mM}{r_2} - G\frac{mM}{r_1}$$

$$\Delta E_p = GmM\left(\frac{1}{r_2} - \frac{1}{r_1}\right)$$

$$\boldsymbol{\Delta E_p = GmM\left(\frac{1}{r_2} - \frac{1}{r_1}\right)}$$

NOTE: Since r_1 is greater than r_2, $\frac{1}{r_1}$ is less than $\frac{1}{r_2}$, therefore $\frac{1}{r_2} - \frac{1}{r_1}$ is positive. Consequently, ΔE is positive.

Example

Calculate the change in gravitational potential energy for a scientific instrument with a mass of 150 kg, when it is moved from ground level to the top of Mount Everest, where the height is 8848 m.

ΔE_p = E_p at the top of Mount Everest – E_p at the surface of the Earth

$$\Delta E_p = -\frac{(6.67 \times 10^{-11}) \times (6.0 \times 10^{24}) \times 150}{(6378000 + 8848)} - \left[-\frac{(6.67 \times 10^{-11}) \times (6.0 \times 10^{24}) \times 150}{6378000}\right]$$

$$\Delta E_p = (6.67 \times 10^{-11}) \times (6.0 \times 10^{24}) \times 150 \times \left(-\frac{1}{6378000 + 8848} + \frac{1}{6378000}\right)$$

$$\Delta E_p = 1.30 \times 10^7 \text{ J}$$

Or

$$\Delta E_p = 13 \text{ MJ}$$

Simple pendulum motion

FIRST-HAND INVESTIGATION

PFAs

H2

PHYSICS SKILLS

H11.1B, D, E
H11.2A, B, C, E
H11.3A, B, C
H12.1A, D
H12.2A, B
H12.3A, C
H12.4A, B, D, E, F
H13.1D, G
H14.1A
H14.2D
H14.3C, D

TR

General resources—Practical reports Practical register Reliability, validity

TR

Risk assessment matrix

■ ***Perform an investigation and gather information to determine a value for acceleration due to gravity using pendulum motion or computer-assisted technology and identify reasons for possible variations from the value 9.8 m s^{-2}***

It is a syllabus requirement that students perform a first-hand investigation and gather information to determine a value of acceleration due to gravity using pendulum motion.

This experiment is discussed extensively in order to provide an example of how students should approach experiments and how experimental data should be processed.

Pendulum motion

Aim

To perform a first-hand investigation using simple pendulum motion to determine a value of acceleration due the Earth's gravity (***g***).

Theory

The period of a pendulum (T) is related to the length of the string of the pendulum (ℓ) by the equation:

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

Equipment/apparatus

Retort stand, boss head and clamp, string and mass bob
Stop watch, ruler

Procedure

1. Set up the apparatus as shown in the diagram on the right:

NOTE: Include a diagram in the procedure when applicable.

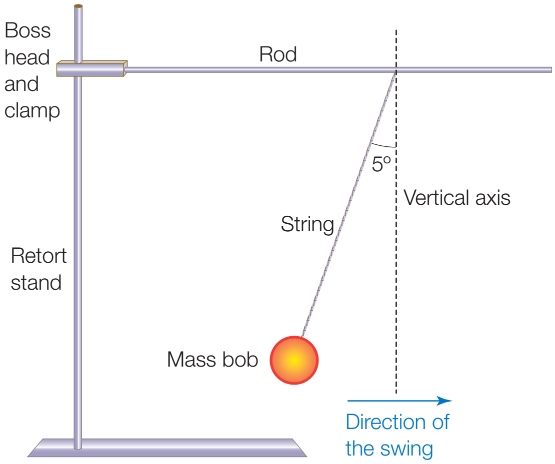


Figure 1.5 Simple pendulum in motion

2. Measure the effective length of the pendulum from the top of the string to the centre of the mass bob. The length should be approximately 1 m.
3. Move the mass so that the string makes an angle of about 5° with the vertical. Release the bob. Use a stop watch to record the time for 10 complete oscillations.
4. Note: If possible, data logging apparatus (with position or velocity sensors) can be used to more accurately find the time taken for the period of the oscillations of the pendulum. The resulting graph of the motion of the pendulum should also show the nature of the motion (simple harmonic), although this is beyond the scope of the present syllabus.

5. Change the length of the string to 0.8 m, and then repeat step 3.
6. Repeat step 4, changing the length of the string to 0.6 m and then to 0.4 m.
7. Use appropriate formulae to find the period of the pendulum and the value of ***g*** (see below).

Results

Record the data in the table below.

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Table 1.2

Length of the string (ℓ) (m)	Time for 10 oscillations (s)	Period (T) (s)
1.00		
0.80		
0.60		
0.40		

NOTE: Divide the time by 10 to calculate the period of the swings, where the period is the time needed by the pendulum for one complete swing.

Calculating *g*:

Two methods can be employed to calculate the value for ***g***.

Method 1: a simpler method

$$T = 2\pi\sqrt{\frac{\ell}{\boldsymbol{g}}} \Rightarrow T^2 = (2\pi)^2\frac{\ell}{\boldsymbol{g}}$$

$$\boldsymbol{g} = \frac{4\pi^2\ell}{T^2}$$

Substitute each period and length into the equation, and calculate ***g***. Then take an average value of the four ***g*** values found.

Method 2: liner transformation

Use a **graph** to plot the relationship between ℓ and T as shown in Figure 1.6 (b). Because ℓ is the **independent variable** and T is the **dependent variable**, we usually plot ℓ on the x-axis and T on the y-axis.

$$T = 2\pi\sqrt{\frac{\ell}{\boldsymbol{g}}}$$

$$T^2 = (2\pi)^2 \times \frac{\ell}{\boldsymbol{g}}$$

$$T^2 = \left(\frac{4\pi^2}{\boldsymbol{g}}\right)\ell$$

The line in Figure 1.6b (opposite) is obtained by drawing in the **line of best fit** through the points. It. can be seen that the grad ient of the line is $\frac{4\pi^2}{\boldsymbol{g}}$. Select any two points on the line to calculate the gradient by using **rise over run**; by equating this gradient with $\frac{4\pi^2}{\boldsymbol{g}}$, the value of ***g*** can be calculated.

If we plot T versus ℓ:

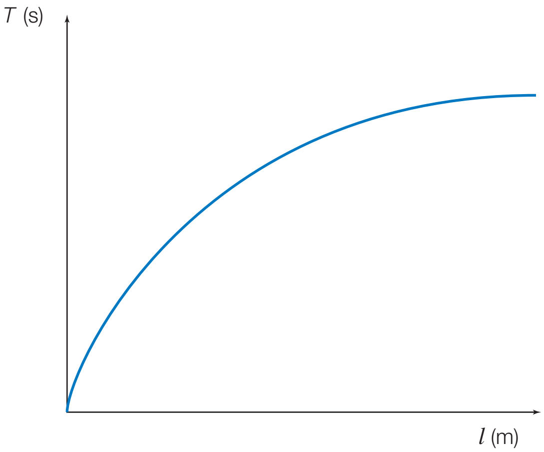


Figure 1.6 (a) T versus ℓ

But if we plot T^2 versus ℓ:

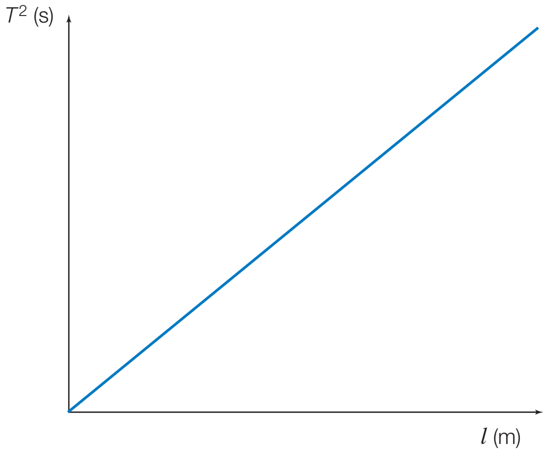


Figure 1.6 (b) T^2 versus ℓ

Discussion

Some possible discussion points include:

1. During the experiment, if the angle of the swing exceeded 10°, the simple pendulum motion would transform into a conical pendulum, which would not be desirable for the calculation of ***g***.
2. The time for 10 oscillations was measured because if the number of oscillations was too small, timing would become very difficult: the human reaction time would be quite large compared to the swing time, resulting in a significant amount of error in timing. If the number of oscillations was too many, then the pendulum would not be able to maintain its 'constant swing' due to air resistance, which also would make the experiment less accurate.
3. The main sources of experimental errors could include:
   (a) Human errors in measurements and timing. In particular, reaction time could be the predominant error in timing.
   (b) Air friction acting on the mass bob while it was swinging.
4. Thus in order to improve the accuracy of the experiment:
   (a) i. Use more accurate devices for measurements. For example, when recording time, use stop watches rather than normal watches. Computer data logging can further improve the accuracy.
   ii. Be familiar with the procedures in order to reduce the reaction times.
   (b) Reduce air currents by closing windows, shielding the pendulum from the surrounding air and using a more streamline mass bob. In fact, a more advanced pendulum experiment is actually done inside a vacuum bulb.
   (c) In general, doing the experiment in a team and repeating the experiment many times will improve the accuracy of the experiment.
5. The possible reasons for the variation of ***g*** values are discussed earlier in this chapter (as required by the syllabus).
   These variations are too small to be detected by the method outlined above.
6. Assess the validity of this experiment by commenting on the way in which any other variables were accounted for.

Conclusion

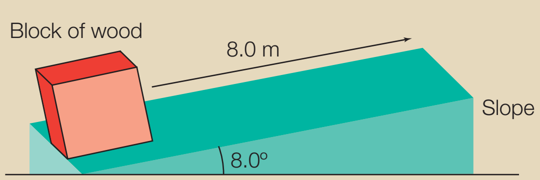
State the value of g found in this pendulum experiment.

NOTE: In general, first-hand investigations (experiments) are just as important as theories. A significant amount of time should be devoted to experiments. This includes relating theories to the experiments, being familiar with procedures, calculations and outcomes of the experiments, and evaluating the accuracy and reliability of the experiments. Issues raised in the first-hand investigation sections of this text should be considered.

CHAPTER REVISION QUESTIONS

For all the questions in this chapter, take the mass of the Earth to be 6.0×10^{24} kg, and the radius of the Earth to be 6378 km. The universal gravitational constant (G) = 6.67×10^{-11} N m^2 kg^{-2}. The mass of the moon is 7.35×10^{22} kg and the radius of the moon is 1738 km.

1. Define the terms 'mass' and 'weight'.
2. Calculate the force of attraction between two neutrons separated by a distance of 1.00×10^{-13} m, knowing the mass of a neutron is 1.675×10^{-27} kg.
3. Calculate the force acting on an 150.0 kg satellite by the Earth, if the satellite orbits 2300 km above the Earth's surface.
4. Suppose there is a force of attraction F acting between objects A and B. If the mass of A is reduced by four times, while the mass of B is reduced by a half, and the distance between them is doubled, what is the new force acting between the two objects?
5. When humans first landed on the surface of the Moon, they had to walk in a jumping fashion. Use relevant calculations to justify this observation.
6. If an unknown planet has a mass that is 10 times heavier than the Earth, and its radius is four times larger than that of the Earth, how would the gravitational acceleration at the surface of this planet compare to that on the Earth?
7. The ratio of the gravitational acceleration on planet Xero to that on the Earth is 3:1; what is the ratio of the weight of an object on this planet to its weight on the Earth?
8. Careful measurements show that the gravitational acceleration (g) is slightly smaller at the equator than that at the poles. Briefly describe two possible reasons that can account for this phenomenon.
9. How much work is done on a 10 g pen when it is picked up from the ground to a table 1.2 m high by a student?
10. (a) A block of wood, with a mass of 390 g, is moved along a slope by a constant force of 7.0 N as shown in the diagram. The slope is inclined at 8.0° to the ground. Ignoring friction, calculate the work done on the wood if it is moved 8.0 m along the slope.



(b) What is the change in potential energy experienced by the block?

11. Calculate the change in gravitational potential energy when a 68.00 kg person is moved from the Earth's surface to the summit of Mount Everest, which is 8848 m in height.

12. Determine the work done on an object, with a mass of 198 g, when it is pushed from a height of 200.0 km above the ground to 3500 km above the same point.

13. Suppose an airbus, with a mass of 15 tonnes, is flying at 250 m s^{-1}, 1.02×10^4 m above the ground level. Determine the total mechanical energy of the plane. Note that mechanical energy includes kinetic energy and gravitational potential energy.

14. Explain why an object within Earth's gravitational field has a negative gravitational potential energy.

15. Plot the change in the gravitational potential energy when a 1.0×10^4 kg rocket is launched from the surface of the Earth to a point which is very far away from the Earth.

SR

Answers to chapter revision questions