South Australian
Certificate of Education

1

Physics
2024

Question booklet 1

- Questions 1 to 11 (60 marks)
- Answer ***all*** questions
- Write your answers in this question booklet
- You may write on page 16 if you need more space
- Allow approximately 65 minutes

Examination information

Materials
- Question booklet 1
- Question booklet 2
- Formula sheet
- SACE registration number label

Instructions
- Use black or blue pen
- You may use a sharp dark pencil for diagrams and other representations
- Approved calculators may be used

Total time: 130 minutes
Total marks: 120

The SACE Board of South Australia acknowledges that this examination was created on Kaurna Land. We acknowledge First Nations Elders, parents, families, and communities as the first educators of their children, and we recognise and value the cultures and strengths that First Nations students bring to the classroom. We respect the unique connection and relationship that First Nations peoples have to Country, and their ever-enduring cultural heritage.

Attach your SACE registration number label here

Government
of South Australia

1. A transformer in a microwave oven converts $220\ \mathrm{V}$ to $2400\ \mathrm{V}$. The output coil of the transformer contains 720 conducting loops.

Source: © Sergey Grishin | Dreamstime.com

(a) Determine the number of conducting loops in the input coil of the transformer.

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___ (2 marks)

(b) The microwave oven produces electromagnetic radiation with a frequency of $2.45\ \mathrm{GHz}$.

Calculate the wavelength of the electromagnetic radiation.

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___ (2 marks)

2. The image below shows a banked section of a curve on a racetrack.

Source: image adapted from © dpa picture alliance | Alamy Stock Photo

Explain how the banked section of the racetrack reduces the car's reliance on friction to move around the curve.

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____ (2 marks)

3. Tethys is a moon of Saturn. Tethys moves in a circular orbit around Saturn with a period of 1.64×10^5 s and an orbital radius of 2.95×10^8 m.

(a) (i) Show that Tethys has an orbital speed of $1.13 \times 10^4 \text{ m s}^{-1}$.

(1 mark)

(ii) Show that Saturn has a mass of 5.65×10^{26} kg.

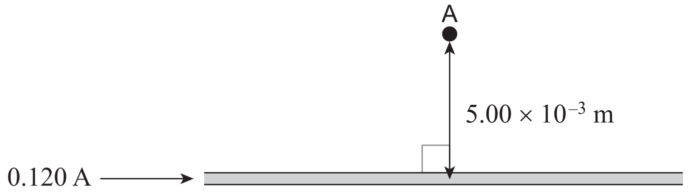
(2 marks)

(b) Tethys has a mass of 6.17×10^{20} kg.

Calculate the magnitude of the gravitational forces between Tethys and Saturn.

(2 marks)

4. A straight conductor carries a current of 0.120 A in the direction shown in the diagram below. Point A is 5.00×10^{-3} m directly above the centre of the conductor.



[This diagram is not drawn to scale.]

(a) State the direction of the magnetic field produced by the current flowing through the conductor.

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____ (1 mark)

(b) Calculate the magnitude of the magnetic field at point A due to the current flowing through the conductor.

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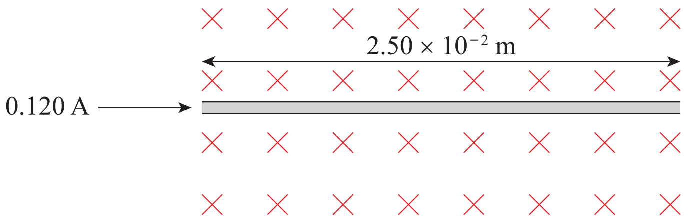
____ (2 marks)

(c) The conductor is placed within a uniform magnetic field that is directed into the plane of the page. The magnitude of the magnetic field is 0.350 T. The length of the conductor within the magnetic field is 2.50×10^{-2} m, as shown in the diagram below.



[This diagram is not drawn to scale.]

Determine the magnitude and direction of the force acting on the conductor due to the magnetic field.

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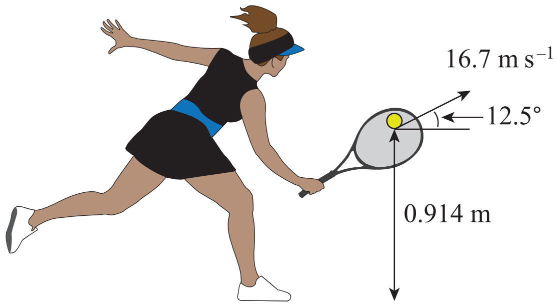
____ (3 marks)

5. A tennis ball was struck with a tennis racket from a height of 0.914 m. After the tennis ball was struck, it moved with a speed of $16.7\ m\,s^{-1}$ at an angle of $12.5°$ above horizontal, as shown in the diagram below.



[This diagram is not drawn to scale.]

(a) Show that the initial vertical speed of the tennis ball after it was struck was $3.61\ m\,s^{-1}$.

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____ (1 mark)

(b) Show that the initial horizontal speed of the tennis ball after it was struck was $16.3\ m\,s^{-1}$.

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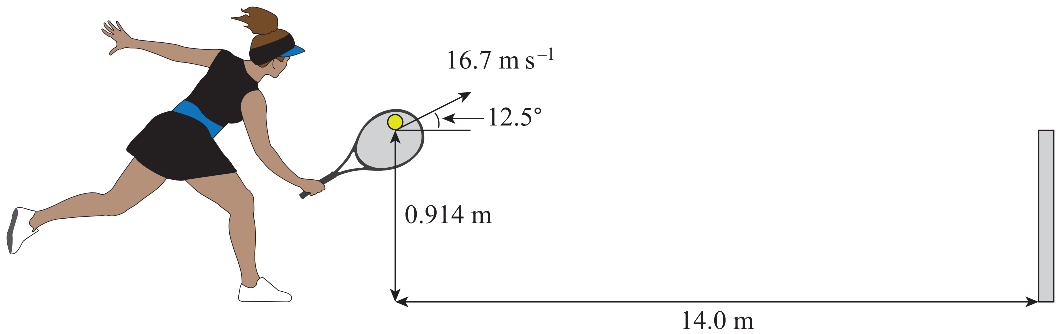
____ (1 mark)

(c) After the tennis ball was struck it moved towards a net. The horizontal distance between the tennis ball and the net was 14.0 m as the tennis ball was struck.



[This diagram is not drawn to scale.]

Show that it took 0.859 seconds for the tennis ball to reach the net.

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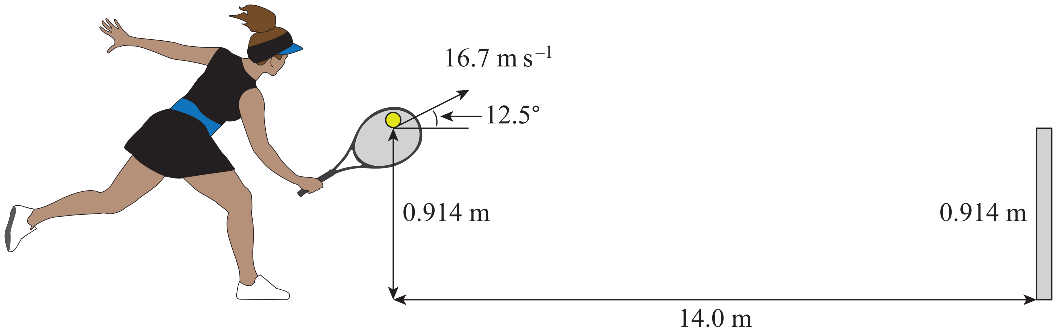
____ (1 mark)

(d) The height of the net is 0.914 m.



[This diagram is not drawn to scale.]

Use calculations to determine whether or not the tennis ball passed over the net.

(3 marks)

(e) The images below show a damaged tennis ball and new tennis ball.

Damaged tennis ball

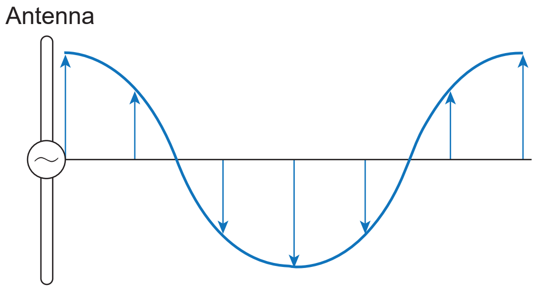
New tennis ball

Source: images adapted from © Pixelrobot | Dreamstime.com

Explain why the damaged tennis ball experiences greater drag forces than the new tennis ball when they move at the same speed.

(2 marks)

6. The diagram below shows electromagnetic radiation that is produced by a vertically oriented transmitting antenna.



[This diagram is not drawn to scale.]

(a) State the plane of polarisation of the electromagnetic wave produced by the transmitting antenna.

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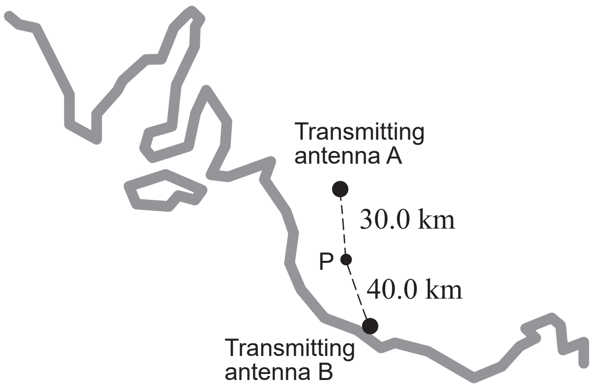
____ (1 mark)

(b) Two vertically oriented transmitting antennas, A and B, produce electromagnetic waves with a wavelength of 62.5 m.

A vertically oriented receiving antenna is positioned at point P.

Point P is 30.0 km from transmitting antenna A and 40.0 km from transmitting antenna B, as shown in the diagram below.



[This diagram is not drawn to scale.]

Determine whether the electromagnetic waves received at point P are at maximum or minimum amplitude.

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____ (3 marks)

7. The South Australian Health and Medical Research Institute uses a PETtrace 880 medical cyclotron to accelerate charged particles.

(a) The frequency of the alternating potential difference of the cyclotron is $27.4\ \text{MHz}$.

Show that the period of the motion of the charged particles in the cyclotron is $3.65 \times 10^{-8}\ \text{s}$.

(2 marks)

(b) The magnetic field in the cyclotron has a magnitude of $1.80\ \text{T}$. A particle with a charge of $1.60 \times 10^{-19}\ \text{C}$ was accelerated in the cyclotron.

Show that the particle has a mass of $1.67 \times 10^{-27}\ \text{kg}$.

(2 marks)

(c) The cyclotron has a radius of $1.70\ \text{m}$.

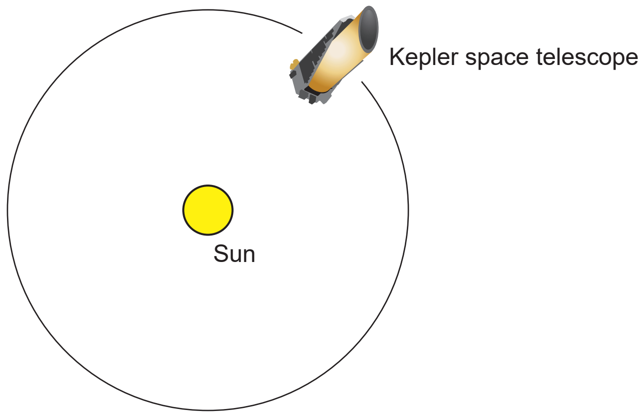
Calculate the kinetic energy of the particle as it exits the cyclotron.

(2 marks)

(d) Explain why increasing the alternating potential difference between the dees does not increase the kinetic energy of the particle as it exits the cyclotron.

(2 marks)

8. The Kepler space telescope is in a circular orbit around the Sun, as shown in the diagram below.



[This diagram is not drawn to scale.]

(a) Show that the relationship between the period, T, of an object in a circular orbit around a mass, M, at orbital radius, r, is given by

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

(3 marks)

(b) The Kepler space telescope has an orbital radius of 1.52×10^{11} m. The Sun has a mass of 1.99×10^{30} kg.

Determine the orbital period of the Kepler space telescope.

(3 marks)

(c)

> The Kepler exoplanet mission was a joint operation between the National Aeronautics and Space Administration (NASA) and the Laboratory for Atmospheric and Space Physics (LASP) to detect exoplanets. The mission involved constructing the Kepler space telescope with an image sensor array specifically designed to collect data on exoplanets from a sample of 150 000 stars in one section of the Milky Way galaxy. NASA oversaw communications with the telescope while LASP coordinated the data management and analysis.
>
> After collecting data for 4 years, the telescope was damaged and was unable to survey the same portion of the Milky Way galaxy. However, instead of ending the mission, scientists collected data from many different parts of the Milky Way galaxy. The telescope eventually collected data from 500 000 stars and identified over 2500 exoplanets. One of the most important discoveries from the Kepler space telescope is that up to half of all the stars in the Milky Way galaxy contain at least one small planet in the 'habitable zone', where liquid water can be found on the surface of the planet.

Explain how the Kepler exoplanet mission demonstrates *one* key concept of science as a human endeavour.

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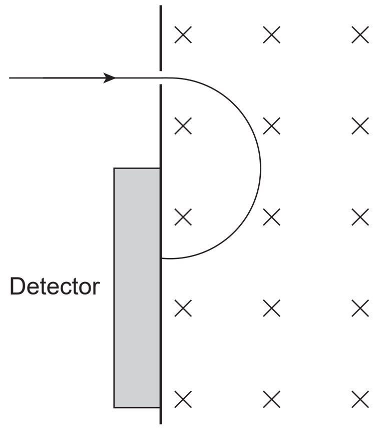
____ (3 marks)

9. An electron is directed into a uniform magnetic field, where it undergoes uniform circular motion. The magnetic field is directed into the plane of the page and is perpendicular to the velocity of the electron. The radius of the circular path of the electrons is determined using a detector, as shown in the diagram below.



[This diagram is not drawn to scale.]

(a) Explain why the electron undergoes uniform circular motion when it is in the uniform magnetic field.

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______________________________________ (2 marks)

(b) The electron moves with a speed of $7.60 \times 10^7 \text{ m s}^{-1}$. The magnitude of the magnetic field is 0.230 T.

Calculate the radius of the circular path of the electron.

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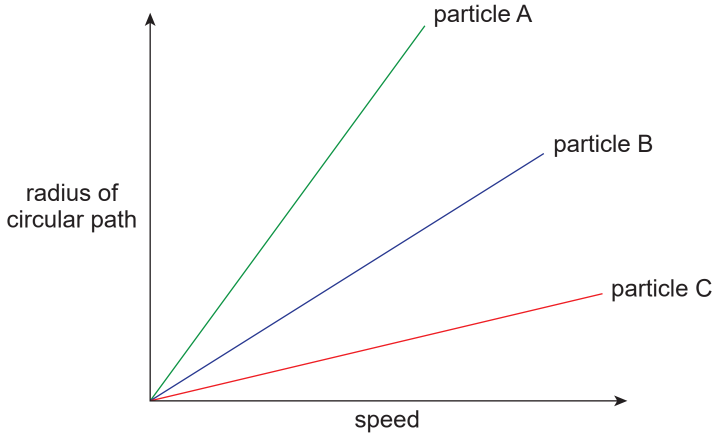
______________________________________ (2 marks)

(c) Three different particles, A, B, and C, undergo circular motion in the magnetic field. Each particle has the same charge. The graph below shows how the radius of the circular path of the particles varies with the speed of the particles.



Use the graph to determine which of the particles had the greatest mass. Justify your answer.

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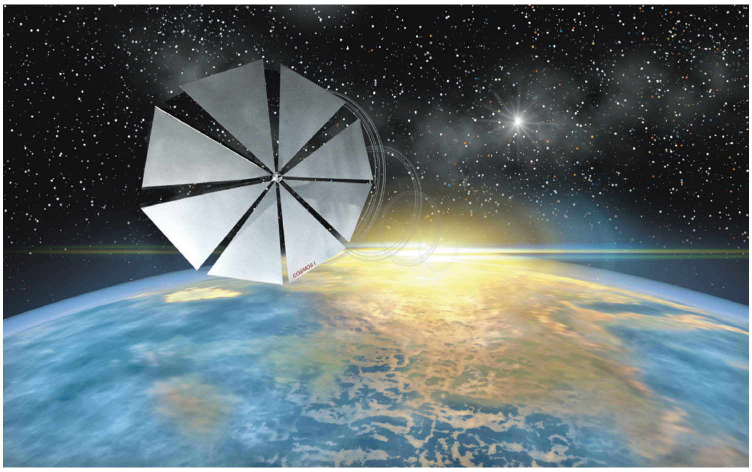
____ (3 marks)

10. A solar sail, like the one shown in the image below, can be used to accelerate spacecraft. A spacecraft is accelerated as photons are reflected from the surface of the solar sail.

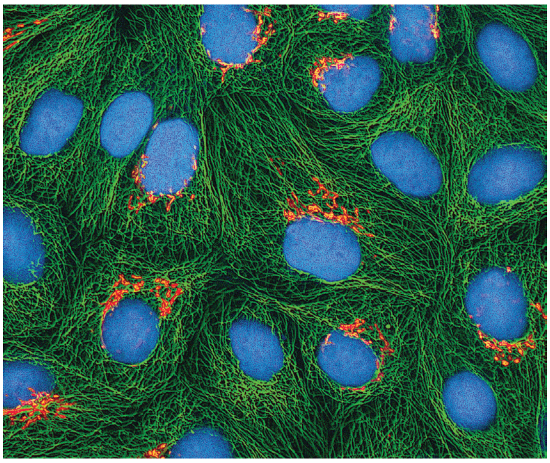


Source: © 15036giovannianselmi | Dreamstime.com

Use the law of conservation of momentum to explain how the reflection of photons can be used to accelerate a solar sail.

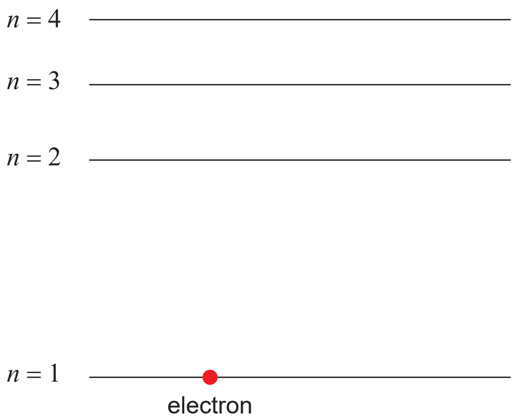
(4 marks)

11. Living cells are sometimes covered in a stain to identify different parts of the cell using fluorescence. The image below shows the fluorescence of cells that have been coated with a stain.



Source: © Science History Images | Alamy Stock Photo

The diagram below shows an electron energy-level diagram with an electron in the $n = 1$ state.



[This diagram is not drawn to scale.]

Use the diagram above to explain the production of multiple photons using fluorescence.

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____ (3 marks)

You may write on this page if you need more space to finish your answers to any of the questions in this question booklet. Make sure to label each answer carefully (e.g. 3(a)(ii) continued).

South Australian Certificate of Education

Physics
2024

Question booklet 2

- Questions 12 to 22 (60 marks)
- Answer ***all*** questions
- Write your answers in this question booklet
- You may write on page 15 if you need more space
- Allow approximately 65 minutes

2

Copy the information from your SACE label here

SEQ	FIGURES	CHECK LETTER	BIN

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12. Cosmic ray detectors are used to detect the speeds of ultra-high-energy particles. Some of these particles are protons.

A proton was detected to have a speed of $0.9956c$.

(a) Show that the Lorentz factor of a proton moving at $0.9956c$ is $\gamma = 10.67$.

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____ (1 mark)

(b) Calculate the magnitude of the relativistic momentum of the proton.

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____ (2 marks)

(c) It took 1.363×10^{8} s for the proton to reach Earth, as measured in the stationary frame of reference of the Earth.

Calculate the time taken for the proton to reach Earth, as measured in the moving frame of reference of the proton.

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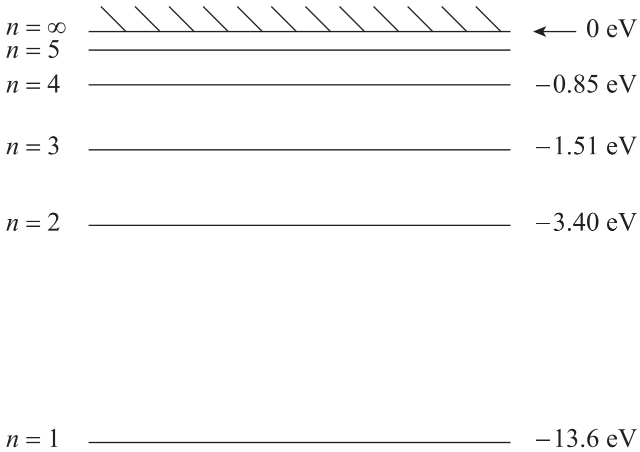
____ (2 marks)

13. The diagram below shows some electron energy levels for a hydrogen atom.



[This diagram is not drawn to scale.]

An electron is in the $n = 4$ energy state.

(a) The electron transitions downwards to the $n = 1$ energy state.

Calculate the frequency of the photon that is emitted as a result of this transition.

(4 marks)

(b) Tick *one* box below to indicate which region of the spectrum the photon from part (a) belongs to.

☐ Infrared

☐ Visible

☐ Ultraviolet

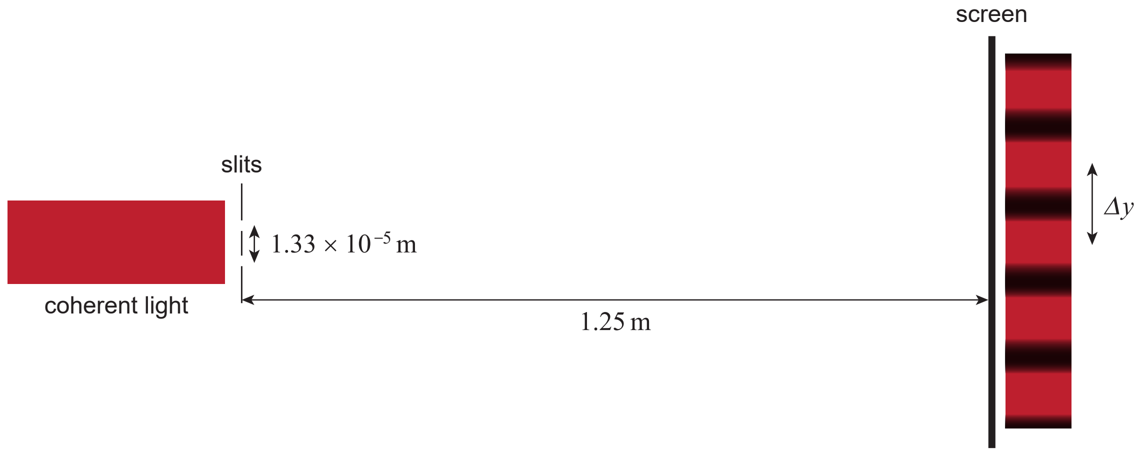
(1 mark)

14. A group of students undertook an experiment using a two-slit interference apparatus.

Coherent light was passed through a pair of slits that were separated by 1.33×10^{-5} m.

The students observed an interference pattern on a screen that was positioned 1.25 m from the slits.

The diagram below shows the experimental apparatus and the interference pattern produced.



[This diagram is not drawn to scale.]

(a) The distance between adjacent bright fringes on the screen was measured to be 5.95×10^{-2} m.

Show that the wavelength of the light used in the experiment was 6.33×10^{-7} m.

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____ (2 marks)

(b) The students replaced the slits with a pair of slits that had a larger separation and repeated the experiment.

State *one* possible difference in the interference pattern that would be observed by the students. Justify your answer.

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____ (2 marks)

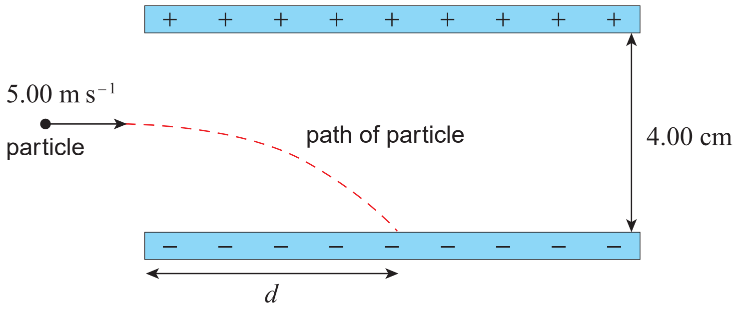
15. A potential difference between two parallel plates produced a uniform electric field. The potential difference between the plates was 3.50×10^4 V and the plates were separated by 4.00 cm.

(a) Show that the magnitude of the electric field between the parallel plates was $8.75 \times 10^5 \text{ Vm}^{-1}$.

(1 mark)

A particle entered the region between the plates, perpendicular to the electric field at a point midway between the plates. The particle has a charge of 1.60×10^{-19} C and an initial speed of 5.00 m s^{-1}. The particle travelled a horizontal distance d before striking the lower plate.

The parallel plates and the path of the particle are shown in the diagram below.



[This diagram is not drawn to scale.]

(b) The particle has a mass of 2.50×10^{-15} kg.

Show that the magnitude of the acceleration of the particle is 56.0 m s^{-2}.

(1 mark)

(c) Show that it took 2.67×10^{-2} s for the particle to strike the lower plate.

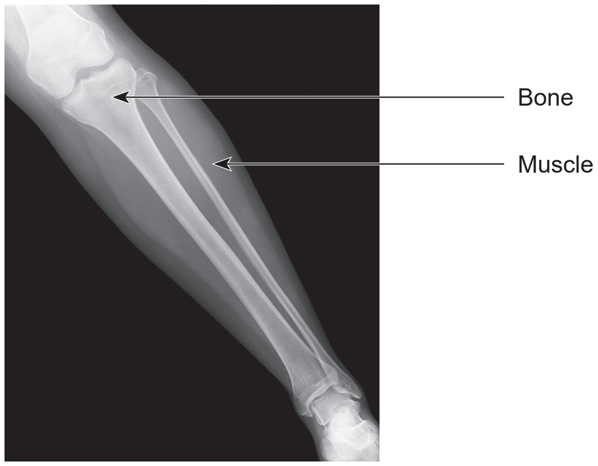
(2 marks)

(d) Calculate the horizontal distance d.

(2 marks)

PLEASE TURN OVER

16. The image below is an X-ray photograph of a human leg showing bone and muscle.

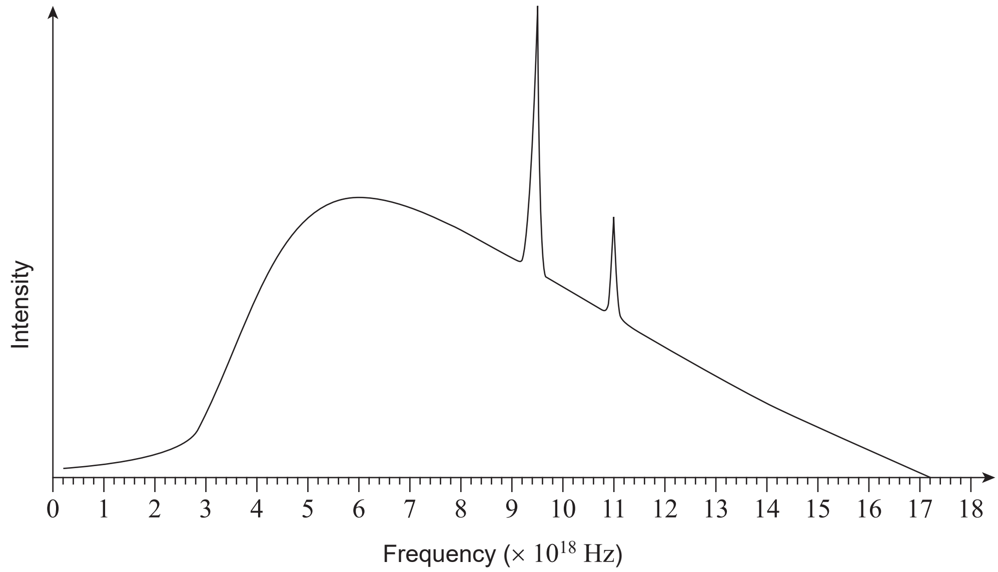


Source: © Science Photo Library | Alamy Stock Photo

(a) Explain why there is greater attenuation of X-rays in the bone than in muscle.

(2 marks)

(b) The X-rays were produced in an X-ray tube. The graph below shows the spectrum of an X-ray tube.



[This diagram is not drawn to scale.]

Use the graph to determine the potential difference across the X-ray tube.

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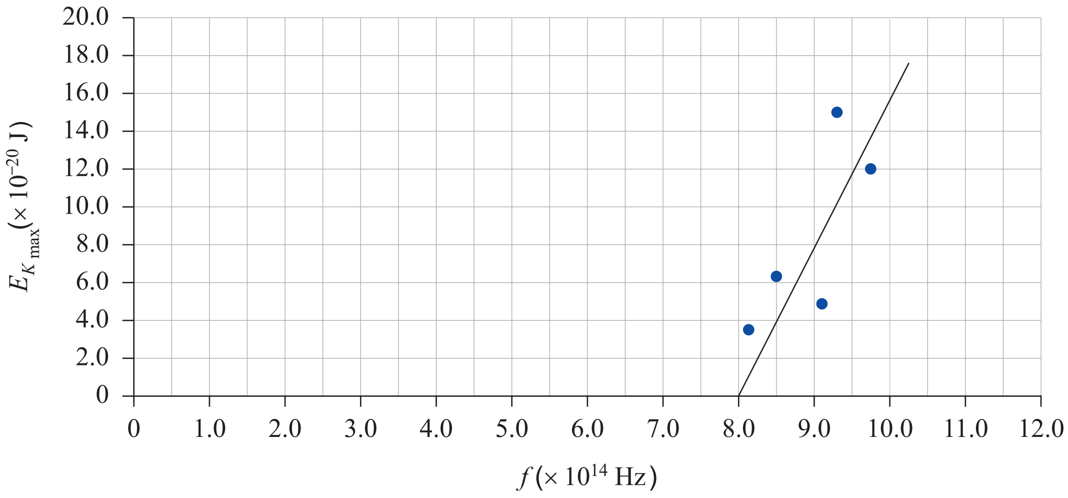
____ (3 marks)

(c) *On the graph above*, sketch a possible spectrum that would be produced if the potential difference across the X-ray tube was *decreased*. (2 marks)

17. The graph below shows the results of an experiment testing the relationship between the maximum kinetic energy of the electrons emitted from a metal surface and the frequency of the incident light in a photoelectric effect apparatus. A line of best fit has been included.



[This diagram is not drawn to scale.]

(a) (i) State the type of error evident in the graph.

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______________________________________ (1 mark)

(ii) Identify *one* possible source of this type of error in this investigation.

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______________________________________ (1 mark)

(b) (i) Use the graph to show that the work function of the metal surface is 5.30×10^{-19} J.

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(b) (ii) The work function of the metal surface is 5.30×10^{-19} J.

Calculate the stopping voltage when light with a frequency of 1.50×10^{15} Hz is incident on the metal surface.

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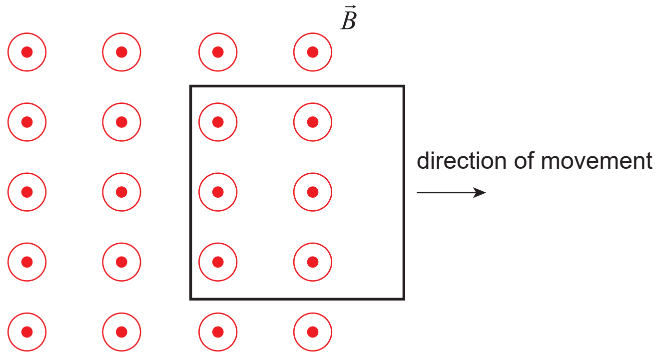
___ (3 marks)

(c) The photoelectric effect apparatus was adjusted so that the light was incident on a different metal surface that has a lower work function.

On the graph on page 8, draw a line showing the relationship between the maximum kinetic energy of the electrons emitted from the surface and the frequency of the incident light for the different metal surface. (2 marks)

18. A square conductive loop passes through a uniform magnetic field, $\vec{B}$, directed out of the plane of the page. The magnetic field is perpendicular to the direction of movement of the loop. The diagram below shows the loop as it leaves the region of the magnetic field.



[This diagram is not drawn to scale.]

(a) Using Lenz's Law, determine the direction of the induced current in the loop as it leaves the region of the magnetic field.

(3 marks)

(b) The magnitude of the magnetic field is 0.900 T and the cross-sectional area of the loop is 1.35×10^{-2} m^2. The loop leaves the region of the magnetic field in 0.160 s.

Calculate the average *emf* induced in the loop.

(3 marks)

19. When X-rays are passed through aluminium foil, they can produce an interference pattern. The interference pattern of the X-rays passing through the aluminium foil is identical to the interference pattern produced by electrons passing through the aluminium foil.

Image A shows the interference pattern produced by the X-rays and image B shows the interference pattern produced by the electrons.

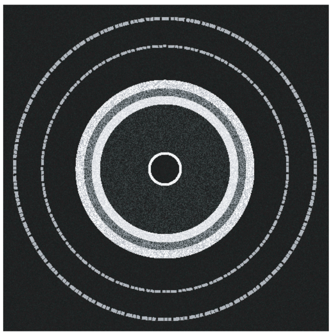


Image A

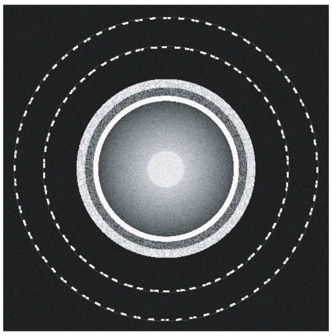


Image B

[This diagram is not drawn to scale.]

The X-rays that produced the interference pattern in Image A had a wavelength of 1.24×10^{-10} m.

Determine the speed of the electrons that produced the interference pattern in Image B.

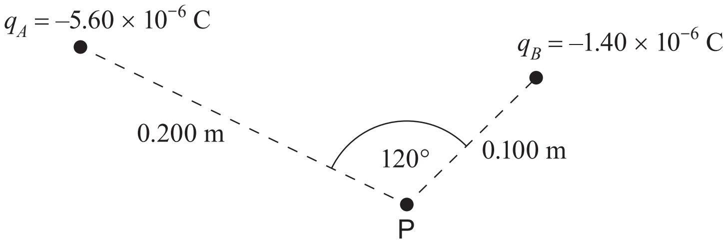
____ (4 marks)

20. The diagram below shows two point charges:

$$q_A = -5.60 \times 10^{-6}\ \text{C}$$

$$q_B = -1.40 \times 10^{-6}\ \text{C}$$

The charges are positioned in a vacuum, in the arrangement shown below, such that point P is $0.200\ \text{m}$ from q_A and $0.100\ \text{m}$ from q_B. The angle between the two charges from point P is $120°$.



[This diagram is not drawn to scale.]

(a) Show that the magnitude of the electric field at point P due to q_B is $1.26 \times 10^6\ \text{NC}^{-1}$.

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____ (1 mark)

(b) Use a vector diagram to determine the magnitude of the net electric field at point P.

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____ (4 marks)

21. A proton and an anti-proton annihilate.

(a) Calculate the energy released in this annihilation.

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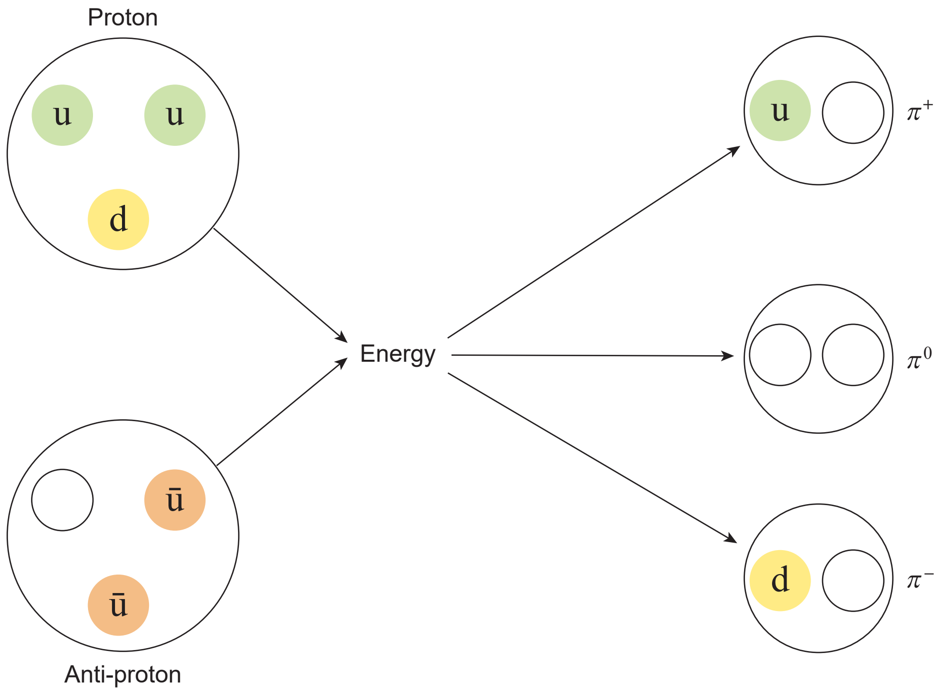
______________________________________ (3 marks)

After the annihilation, a positively charged pion (π^+), a neutral pion (π^0), and a negatively charged pion (π^-) are produced.

The total number and types of quarks and anti-quarks in the proton and anti-proton before the annihilation are found in the pions after the annihilation.

The annihilation and the pions are shown in the diagram below with some quarks and anti-quarks missing.



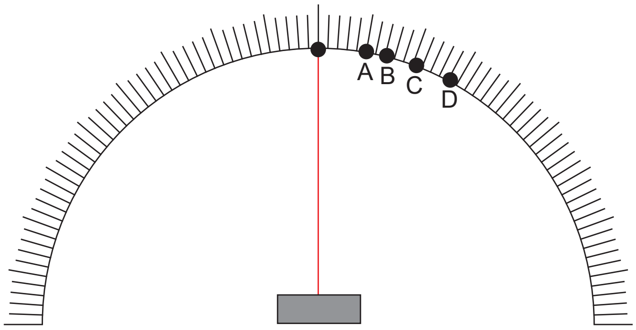
[This diagram is not drawn to scale.]

A proton is a baryon, an anti-proton is an anti-baryon, and pions are mesons.

(b) Complete the diagram above by entering the missing quarks and anti-quarks. (3 marks)

22. A student uses a diffraction grating to observe the first order visible spectrum of hydrogen gas.

The student observes visible lines at points A, B, C, and D, as shown in the diagram below.



[This diagram is not drawn to scale.]

The visible lines observed by the student correspond to the transitions ending at the $n = 2$ electron energy level in hydrogen.

Explain which of the points in the diagram above corresponds to the transition from $n = 3$ to $n = 2$.

____ (3 marks)

You may write on this page if you need more space to finish your answers to any of the questions in this question booklet. Make sure to label each answer carefully (e.g. 17(b)(ii) continued).

PHYSICS FORMULA SHEET

Vectors are indicated by arrows. If only the magnitude of a vector quantity is used, the arrow is not used.

Symbols of common quantities

acceleration	$\vec{a}$	force	$\vec{F}$	magnetic flux	Φ	time	t
charge	q	frequency	f	mass	m	velocity	$\vec{v}$
displacement	$\vec{s}$	kinetic energy	E_K	momentum	$\vec{p}$	wavelength	λ
electric current	I	length	l	period	T		
electromotive force	ε	magnetic field	$\vec{B}$	potential difference	ΔV		

Magnitude of physical constants

acceleration due to gravity at the Earth's surface	$g = 9.80\ \mathrm{m\,s^{-2}}$	Planck's constant	$h = 6.63 \times 10^{-34}\ \mathrm{J\,s}$
constant of universal gravitation	$G = 6.67 \times 10^{-11}\ \mathrm{N\,m^2\,kg^{-2}}$	charge of an electron	$e = 1.60 \times 10^{-19}\ \mathrm{C}$
speed of light in a vacuum	$c = 3.00 \times 10^{8}\ \mathrm{m\,s^{-1}}$	mass of an electron	$9.11 \times 10^{-31}\ \mathrm{kg}$
		mass of a proton	$1.67 \times 10^{-27}\ \mathrm{kg}$
Coulomb's Law constant	$\frac{1}{4\pi\varepsilon_0} = 8.99 \times 10^{9}\ \mathrm{N\,m^2\,C^{-2}}$	mass of Earth	$5.97 \times 10^{24}\ \mathrm{kg}$
constant for the magnetic field around a conductor	$\frac{\mu_0}{2\pi} = 2.00 \times 10^{-7}\ \mathrm{T\,m\,A^{-1}}$	mean radius of Earth	$6.37 \times 10^{6}\ \mathrm{m}$

Topic 1: Motion and relativity

$\vec{v} = \vec{v}_0 + \vec{a}t$	$\vec{v}$ = velocity at time t $\vec{v}_0$ = initial velocity	$v = \frac{2\pi r}{T}$	
$\vec{s} = \vec{v}_0 t + \frac{1}{2}\vec{a}t^2$		$\vec{g} = \frac{\vec{F}}{m}$	$\vec{g}$ = gravitational field strength
$v^2 = v_0^2 + 2as$		$F = G\frac{m_1 m_2}{r^2}$	r = distance between masses m_1 and m_2
$v_H = v\cos\theta$ $v_V = v\sin\theta$	θ = angle to horizontal	$v = \sqrt{\frac{GM}{r}}$	M = mass of object orbited by satellite r = radius of orbit
$E_K = \frac{1}{2}mv^2$		$T^2 = \frac{4\pi^2}{GM}r^3$	
$\vec{a} = \frac{\Delta\vec{v}}{\Delta t}$		$\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$	γ = Lorentz factor
$\vec{F} = m\vec{a}$		$t = \gamma t_0$	t_0 = time interval in the moving frame of reference
$\vec{F} = \frac{\Delta\vec{p}}{\Delta t}$		$l = \frac{l_0}{\gamma}$	l_0 = length in the moving object's frame of reference
$\vec{p} = m\vec{v}$		$p = \gamma m_0 v$	m_0 = mass in the frame of reference where the object is stationary
$a = \frac{v^2}{r}$	r = radius of circle		

Topic 2: Electricity and magnetism

$F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$	r = distance between charges q_1 and q_2	$F = qvB\sin\theta$	θ = angle between magnetic field $\vec{B}$ and velocity $\vec{v}$
$\vec{E} = \frac{\vec{F}}{q}$	$\vec{E}$ = electric field	$r = \frac{mv}{qB}$	r = radius of circle
$E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}$	r = distance from charge	$T = \frac{2\pi m}{qB}$	
$W = q\Delta V$	W = work done	$E_K = \frac{q^2 B^2 r^2}{2m}$	r = radius at which ions emerge from cyclotron
$E = \frac{\Delta V}{d}$	d = distance between parallel plates	$f = \frac{1}{T}$	f = frequency of the alternating potential difference
$\vec{a} = \frac{q\vec{E}}{m}$		$\Phi = BA_{\perp}$	$A_{\perp}$ = area perpendicular to the magnetic field
$B = \frac{\mu_0}{2\pi}\frac{I}{r}$	r = distance from conductor	$\varepsilon = \frac{N\Delta\Phi}{\Delta t}$	N = number of conducting loops
$F = IlB\sin\theta$	θ = angle between magnetic field and direction of current	$\frac{V_{\text{input}}}{V_{\text{output}}} = \frac{N_{\text{input}}}{N_{\text{output}}}$	V = potential difference in transformer coils

Topic 3: Light and atoms

$v = f\lambda$		$W = hf_0$	W = work function of the metal f_0 = threshold frequency
$d\sin\theta = m\lambda$	d = distance between slits θ = angular position of m^{th} maximum m = integer (0, 1, 2, …)	$E_{K\max} = eV_s$	$E_{K\max}$ = maximum kinetic energy of electrons V_s = stopping voltage
$\Delta y = \frac{\lambda L}{d}$	Δy = distance between adjacent minima or maxima L = slit-to-screen distance	$E_{K\max} = hf - W$	
$E = hf$	E = energy of photon	$f_{\max} = \frac{e\Delta V}{h}$	ΔV = potential difference across the X-ray tube
$p = \frac{h}{\lambda}$		$E = \Delta mc^2$	E = energy

Table of prefixes

Prefix	Symbol	Value
tera	T	10^{12}
giga	G	10^{9}
mega	M	10^{6}
kilo	k	10^{3}
centi	c	10^{-2}
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}
femto	f	10^{-15}

Quarks

Quark	Symbol	Charge (e)
Up	u	$^2/_3$
Down	d	$^{-1}/_3$
Strange	s	$^{-1}/_3$
Charm	c	$^2/_3$
Top	t	$^2/_3$
Bottom	b	$^{-1}/_3$