Government of **Western Australia**
School Curriculum and Standards Authority

ATAR course examination, 2021

Question/Answer booklet

PHYSICS

Place one of your candidate identification labels in this box.

Ensure the label is straight and within the lines of this box.

WA student number: In figures | | | | | | | | |

In words ______________________________

____

Time allowed for this paper

Reading time before commencing work: ten minutes
Working time: three hours

Number of additional answer booklets used (if applicable):

Materials required/recommended for this paper

To be provided by the supervisor
This Question/Answer booklet
Formulae and Data booklet

To be provided by the candidate
Standard items: pens (blue/black preferred), pencils (including coloured), sharpener, correction fluid/tape, eraser, ruler, highlighters

Special items: up to three calculators, which do not have the capacity to create or store programmes or text, are permitted in this ATAR course examination, drawing templates, drawing compass and a protractor

Important note to candidates

No other items may be taken into the examination room. It is **your** responsibility to ensure that you do not have any unauthorised material. If you have any unauthorised material with you, hand it to the supervisor **before** reading any further.

Ref: 21-068

PHY

2022/5158
Web version of 2021/62180

Structure of this paper

Section	Number of questions available	Number of questions to be answered	Suggested working time (minutes)	Marks available	Percentage of examination
Section One Short response	12	12	50	53	30
Section Two Problem-solving	7	7	90	93	50
Section Three Comprehension	2	2	40	38	20
				Total	100

Instructions to candidates

1. The rules for the conduct of the Western Australian external examinations are detailed in the *Year 12 Information Handbook 2021: Part II Examinations*. Sitting this examination implies that you agree to abide by these rules.

2. Write your answers in this Question/Answer booklet preferably using a blue/black pen. Do not use erasable or gel pens.

3. You must be careful to confine your answers to the specific questions asked and to follow any instructions that are specific to a particular question.

4. When calculating or estimating answers, show all your working clearly. Your working should be in sufficient detail to allow your answers to be checked readily and for marks to be awarded for reasoning.

   In calculations, give final answers to three significant figures and include appropriate units where applicable.

   In estimates, give final answers to a maximum of two significant figures and include appropriate units where applicable.

5. Supplementary pages for planning/continuing your answers to questions are provided at the end of this Question/Answer booklet. If you use these pages to continue an answer, indicate at the original answer where the answer is continued, i.e. give the page number.

6. The Formulae and Data booklet is not to be handed in with your Question/Answer booklet.

Section One: Short response **30% (53 Marks)**

This section has **12** questions. Answer **all** questions. Write your answers in the spaces provided.

When calculating numerical answers, show your working or reasoning clearly. Give final answers to **three** significant figures and include appropriate units where applicable.

When estimating numerical answers, show your working or reasoning clearly. Give final answers to a maximum of **two** significant figures and include appropriate units where applicable.

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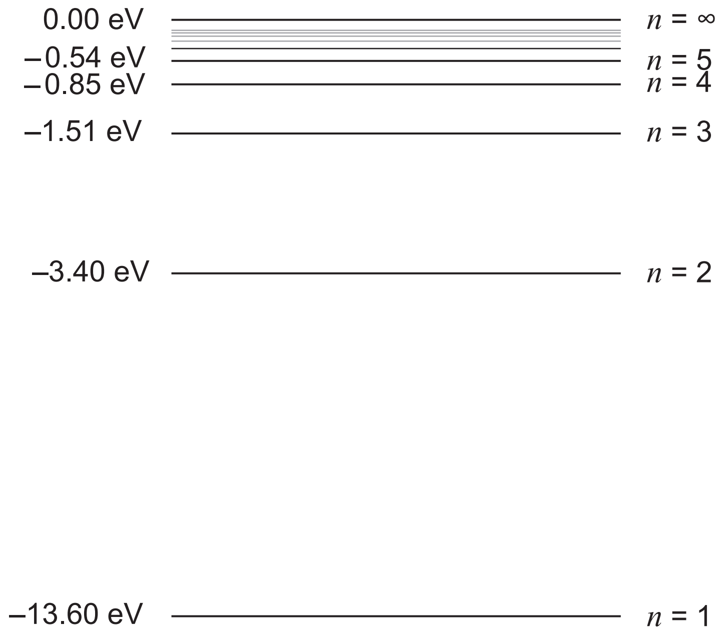
Suggested working time: 50 minutes.

Question 1 **(4 marks)**

Some energy levels, n, for hydrogen atoms are shown in the diagram below.



Electrons with 12.2 eV of energy are incident on the hydrogen atoms. Calculate the energies of all scattered electrons in eV.

Answer ______________________________ eV

Question 2 **(3 marks)**

Using information from the Formulae and Data Booklet, calculate the mass of a bottom quark in kg.

Answer ______________ kg

Question 3 **(4 marks)**

A DC electric motor is shown in the diagram below. A current of 3.50 A is running through the single rectangular loop, which is pictured at 45.0° to a uniform 1.52 mT horizontal magnetic field.

Calculate the magnitude and give the direction of the forces on sides AB and CD of the loop, using the directions provided in the table below. Write your answers in the table below.

Side	Force (N)	Direction (up, down, left, right, into the page, out of the page, no force)
AB		
CD		

Question 4 **(5 marks)**

A proton in a linear particle accelerator is given an energy of 0.100 TeV. Using the equation for mass-energy equivalence, calculate the speed of the proton in terms of c. Give your answer to five significant figures.

Answer ______________ c

Question 5 **(4 marks)**

(a) State **two** main differences between hadrons and leptons. (2 marks)

One	
Two	

(b) Identify an example of a hadron and a lepton from the list provided and write your choice in the spaces below. (2 marks)

(i) Proton (ii) Meson (iii) Tau neutrino (iv) Neutron (v) Muon (vi) Baryon

Hadron: ______________

Lepton: ______________

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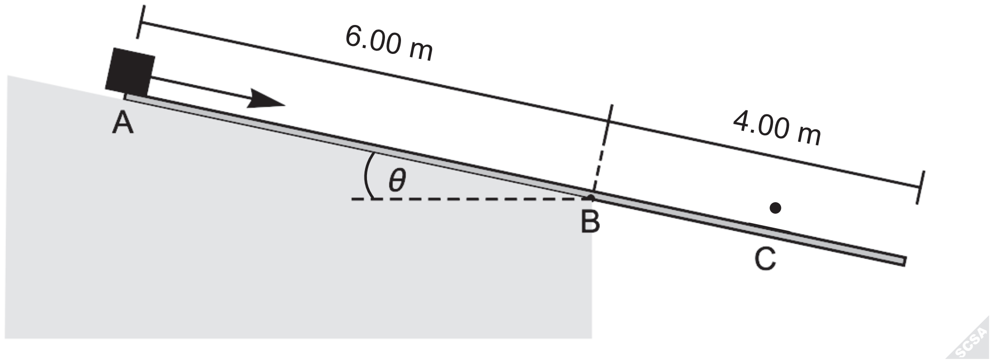
Question 6 **(5 marks)**

A student is set the task of determining the slope of a concrete structure using only a 15.0 kg beam, a ruler, a 5.00 kg mass with one smooth face and one rough face, and a stopwatch. She places the 10.0 m long uniform beam on top of the sloping structure with 4.00 m of the beam hanging over the end of the structure as shown in the cross-sectional diagram below. The student then places the 5.00 kg mass rough side down at increasing distances from B until the beam starts to tip over. She marks that place as C. The student then lets the 5.00 kg mass slide on its smooth side down the smooth beam from rest at A. She measures the time to reach C as 3.30 s.



(a) Calculate the distance between A and C. (3 marks)

Answer ______________ m

(b) Ignoring friction, calculate the angle of the slope measured from the horizontal. (2 marks)

Answer ______________ °

Question 7 **(4 marks)**

A bobo doll, as shown below, can never be tipped over. Even if its head is held on the ground, it will stand back up when released. Explain how this works. You must include in your answer the relevant conditions required for static equilibrium. Use the diagram on the right to illustrate your answer.

Question 8 **(4 marks)**

Complete the following table for an anti-proton.

Name	Symbol	Quark composition	Electric charge	Mass (GeV/c^2)
proton	p	uud	1	0.938
anti-proton				

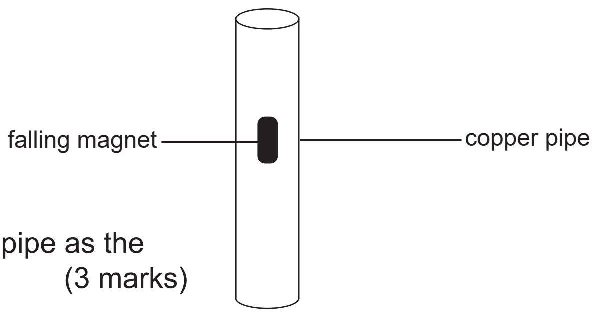
Question 9 **(5 marks)**

A space station is shaped like a huge hollow doughnut that is rotating uniformly. The outer radius is 4.60×10^2 m. What is the period of rotation of the station if a person standing on the outer wall inside the station experiences the same weight force she would experience on Earth?

Answer ______________ s

Question 10 **(4 marks)**

A very strong 55.0 g neodymium magnet is dropped vertically down a hollow copper pipe. The eddy currents induced in the copper provide an upwards force which enables the magnet to reach a terminal velocity of 8.51 cm s^{-1}.



(a) Calculate the power supplied as heat to the pipe as the magnet falls at this velocity. (3 marks)

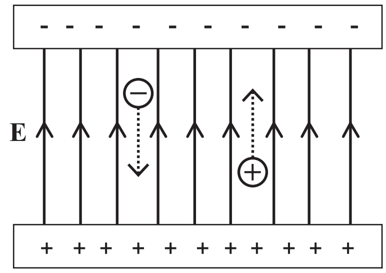
Answer ______________ W

(b) Silver has a higher electrical conductivity than copper. How would your answer to part (a) change if the pipe was now made of silver? Circle your answer. (1 mark)

(i) Increase (ii) Decrease (iii) No change

Question 11 **(7 marks)**

High-speed charged particles have many technological and scientific applications. One way of accelerating these particles to high speeds is by using strong electric fields.



(a) Through what potential difference would a proton at rest need to be accelerated for it to achieve a speed of 6.00×10^5 m s^{-1}? (3 marks)

Answer ________________ V

(b) What would be the final velocity of an electron accelerated from rest across the same potential difference? If you could not obtain an answer to part (a), use 2.00 kV as the potential difference. (3 marks)

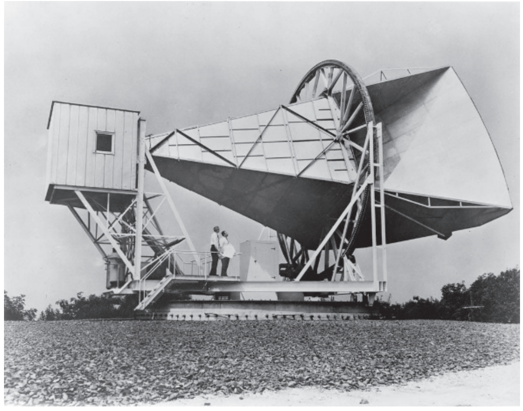
Answer ________________ m s^{-1}

(c) What is the ratio of the kinetic energies between the proton and electron once they cross the same potential difference? (1 mark)

Answer ________________

Question 12 **(4 marks)**

Cosmic Microwave Background radiation (CMB) was first observed in 1965 by Arno Penzias and Robert Wilson at the Bell Telephone Laboratories in Murray Hill, New Jersey. They had built a Dicke radiometer that they intended to use for radio astronomy and satellite communication experiments. They detected the CMB in every direction they pointed their radiometer.



(a) Briefly explain the origin of CMB as part of the Big Bang theory. (2 marks)

(b) How does the study of CMB provide evidence that the universe is expanding? (2 marks)

End of Section One

Section Two: Problem-solving **50% (93 Marks)**

This section has **seven** questions. Answer **all** questions. Write your answers in the spaces provided.

When calculating numerical answers, show your working or reasoning clearly. Give final answers to **three** significant figures and include appropriate units where applicable.

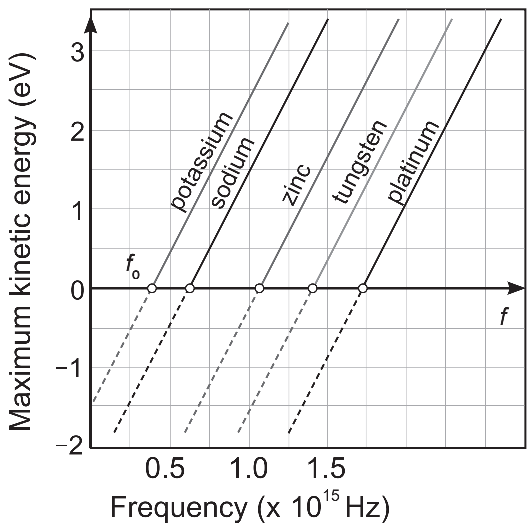
When estimating numerical answers, show your working or reasoning clearly. Give final answers to a maximum of **two** significant figures and include appropriate units where applicable.

Supplementary pages for planning/continuing your answers to questions are provided at the end of this Question/Answer booklet. If you use these pages to continue an answer, indicate at the original answer where the answer is continued, i.e. give the page number.

Suggested working time: 90 minutes.

Question 13 **(13 marks)**

The photoelectric effect uses light to liberate electrons from metals. The graph of the maximum kinetic energy of these liberated electrons from different metals plotted against the frequency of the incident light is shown below.



(a) Estimate the threshold frequency for potassium from the graph above. (2 marks)

Answer ______________ Hz

Each metal has a work function that describes the minimum amount of energy required to liberate an electron from the surface of that metal.

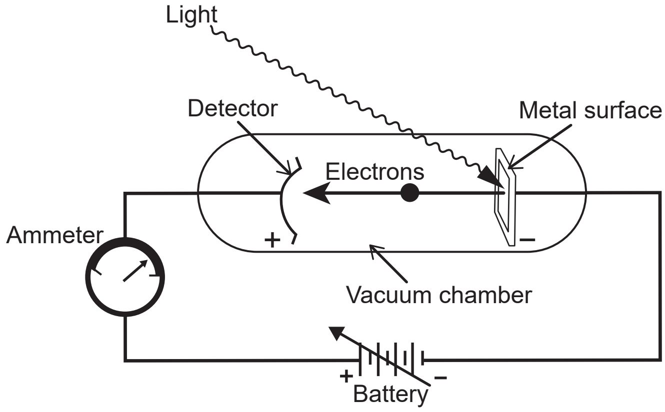
(b) Estimate the work function for potassium from the graph above. (2 marks)

Answer ______________ eV

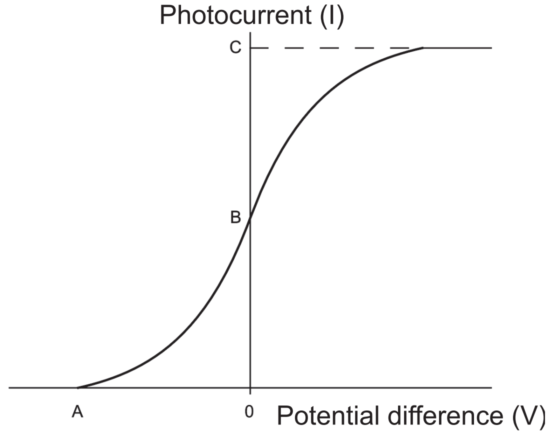
(c) Using your value from part (b), estimate the maximum velocity of a liberated electron if light with a frequency of 1.20×10^{15} Hz shines on a potassium metal plate. Give your answer to two significant figures. (6 marks)

Answer ______________ m s^{-1}

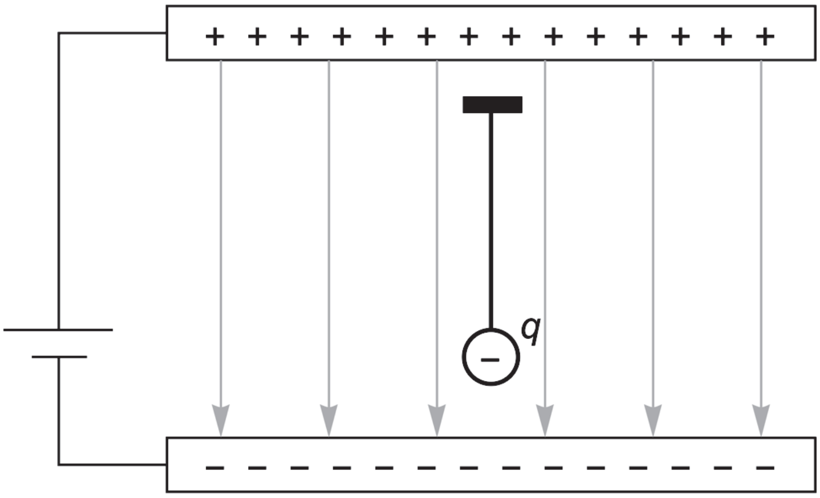
The diagram below shows how the kinetic energy of the liberated electrons is measured. The ammeter measures the photocurrent and the battery can reverse and vary the potential difference between the metal plate and the detector. The potential is increased until the ammeter reads zero.



(d) Below is a graph of photocurrent versus potential difference. On this graph, draw the resulting curve when light of the same frequency but lower power is shone on the same metal. (3 marks)



Question 14 **(13 marks)**



A 0.200 kg metal sphere with a net negative charge of 2.72 mC is suspended by a 0.800 m long almost massless string in a uniform electric field. The plates of the field are 1.20 m apart and the potential difference between the positive top and the negative bottom plate is 1.80×10^2 V.

(a) Calculate the strength of the electric field. (1 mark)

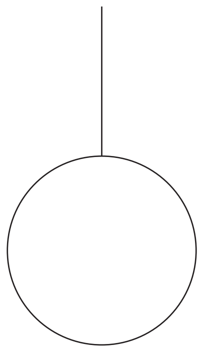
Answer ______________ V m^{-1}

(b) Calculate the tension in the string. (4 marks)

Answer ______________ N

(c) The sphere is pulled to one side and released. At the bottom of the swing, the sphere is travelling at 2.80 m s^{-1}.

(i) Draw a free body diagram of the forces acting on the sphere in this position. Label all forces. Do **not** show the net force acting on the sphere. (3 marks)



(ii) Derive an expression for the net force acting on the sphere in terms of the forces in your diagram. (1 mark)

F_{net} =

(iii) Calculate the tension in the string at the bottom of its swing. (4 marks)

Answer ______________ N

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Question 15 **(11 marks)**

A 42.5 kg gymnast performs her dismount from the 1.25 m high beam. She leaves the beam with a velocity of 3.10 m s^{-1} at an angle of 55.0° to the horizontal.

(a) Calculate the vertical and horizontal components of her launch velocity. (2 marks)

Answer v_V ____________________ m s^{-1} Answer v_H ____________________ m s^{-1}

(b) Calculate the time it takes for her to reach the ground, assuming she is vertical at impact. (5 marks)

Answer ______________ s

(c) Calculate her range R. (2 marks)

Answer ______________ m

(d) Calculate the gymnast's kinetic energy at the top of her flight. (2 marks)

Answer ______________ J

Question 16 **(18 marks)**

Light does not travel at the same speed in all materials. When travelling from air into a different material, light slows down and refracts. The amount of refraction is determined by the refractive index (n) of the material. It is calculated using the following equation:

$$n = \frac{c}{v}$$

where v is the speed of light in the material and c is the speed of light in a vacuum.

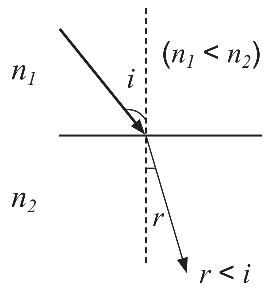
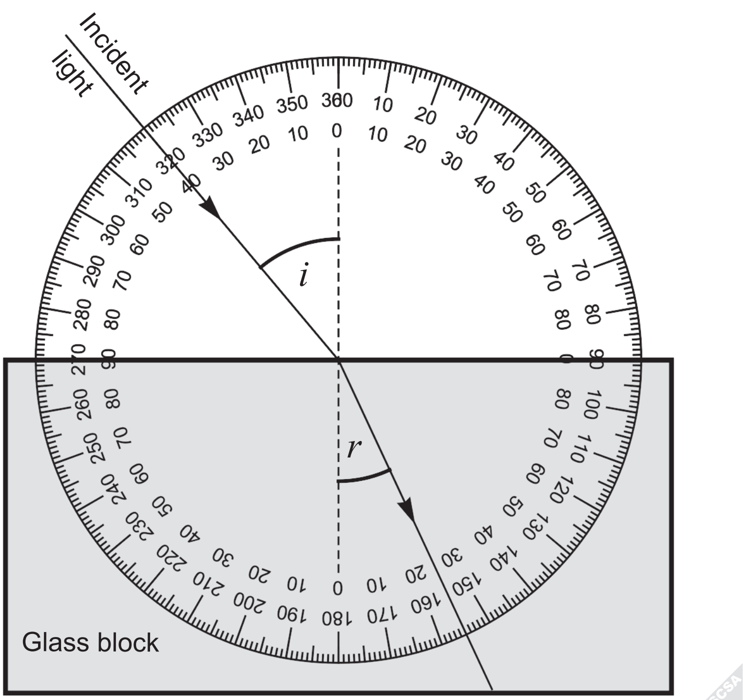


Figure 1: Light refracting at the boundary between two media.

From Figure 1, the following relationship can be demonstrated. This is known as Snell's Law.

$$n_1 \sin i = n_2 \sin r$$

A group of students try to determine the refractive index of a glass block by measuring the refraction of light incident on the block. Below is a schematic of their experiment showing the angle of incidence i and the angle of refraction r.

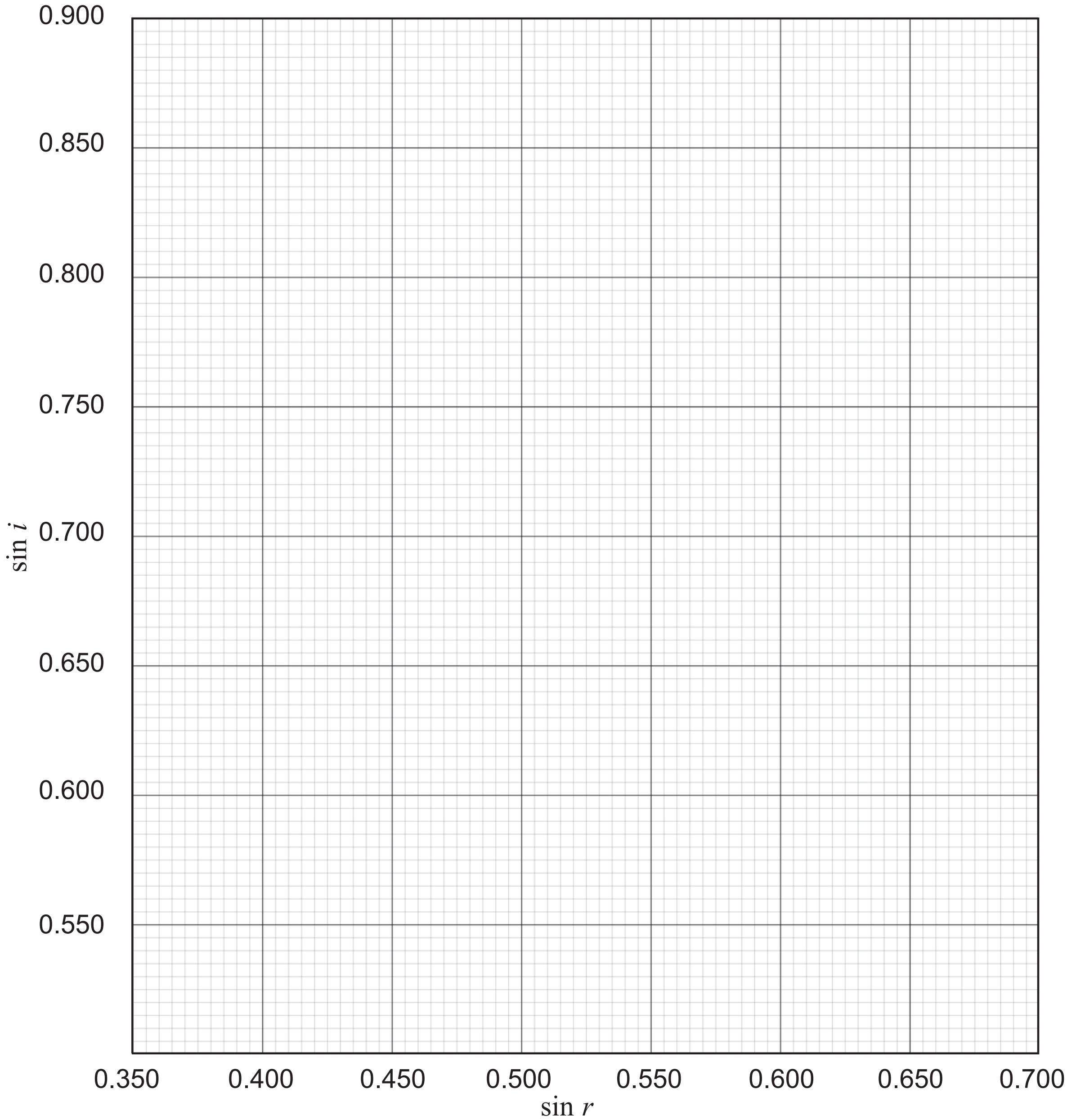


They varied the angle and found that white light produced a rainbow effect, which made measuring r very difficult. So they changed the light source to a monochromatic red light laser. They obtained the results in the table below.

Angle	$i \pm 1°$	35	40	45	50	55
	$\sin i$					
Angle	$r \pm 1°$	23	25	28	31	33
	$\sin r$					

(a) Complete the table, giving the values of sine to three significant figures. (2 marks)

(b) Graph $\sin i$ vs $\sin r$ on the graph below. Include a line of best fit. (3 marks)



A spare grid is provided at the end of this Question/Answer booklet. If you need to use it, cross out this attempt and indicate that you have redrawn it on the spare grid.

Question 16 (continued)

(c) The refractive index of air (n_1) is 1.00. Using your line of best fit, determine the refractive index of the prism (n_2). Indicate clearly which two points on your line of best fit you used in your calculation. Give your answer to two significant figures. (4 marks)

Answer ______________

(d) There are two phenomena described in this question that support the wave behaviour of light. List them below. (2 marks)

One: ______________________________

Two: ______________________________

(e) The tolerance for all angles was ± 1°. How does the percentage error change as the angle measured increases? Use calculations in your answer. (3 marks)

(f) Using the following trigonometric identity, calculate the percentage error of the sine of an angle of incidence of 50.0°. (4 marks)

$$\sin(A \pm B) = \sin A \cos B \pm \cos A \sin B$$

Answer ____________________ %

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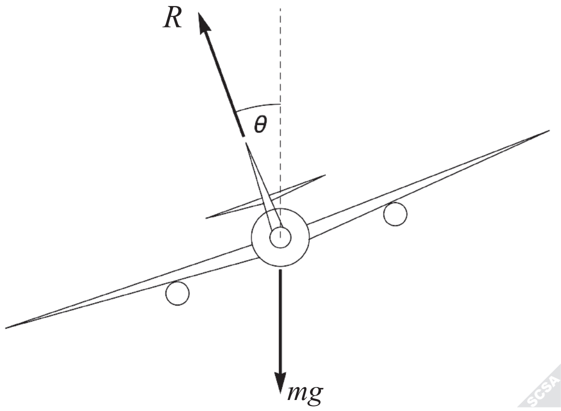
Question 17 **(13 marks)**

Aeroplanes are designed to produce an upthrust that counters their weight force. This allows them to maintain altitude. The magnitude of this upthrust (R) is directly proportional to the forward speed of the aircraft. It always acts perpendicular to the wings. When changing direction, the aeroplane banks in a circular path. A free body diagram of a banking aeroplane is shown below.



(a) Draw a vector diagram showing how the weight force and the upthrust produce a resultant centripetal force. Label the resultant force and include the angle Θ shown in the free body diagram. (3 marks)

(b) Calculate the centripetal force on a 5.60×10^3 kg aeroplane banking at an angle of 15.0° to the vertical while maintaining constant altitude. (3 marks)

Answer ______________ N

(c) If the aeroplane is travelling at 4.50×10^2 km h^{-1}, calculate the radius of the circular path it takes when banking while maintaining constant altitude. (3 marks)

Answer ______________ m

(d) With reference to your vector diagram in part (a) and the text, explain why aeroplanes need to increase their speed to maintain altitude when banking. (4 marks)

Question 18 **(15 marks)**

In an experiment, two neutrally-charged subatomic particles, A and B, each of mass m, are fired directly toward each other. Both have a speed of 0.600 c, as seen by the observer O shown in Figure 1. The particles collide and become one particle, C, which O observes to be stationary. No energy is lost due to interactions with the environment and no other particles, e.g. photons, are emitted.

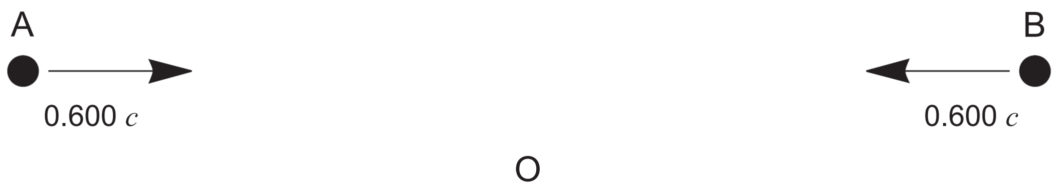


Figure 1: Two particles of equal mass and opposite velocities collide

(a) Using conservation of relativistic energy, calculate the mass of the combined particle m_C. Give your answer in terms of m, the mass of each of the original particles. (4 marks)

Answer ________________ m

(b) Explain why the velocity of the combined particle has to be 0 m s^{-1}. (2 marks)

____

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For parts (c) and (d) consider the same collision viewed by an observer X, who is moving with a velocity of −0.600 c (i.e. the same velocity that Particle B had before the collision). X maintains this velocity after the collision.

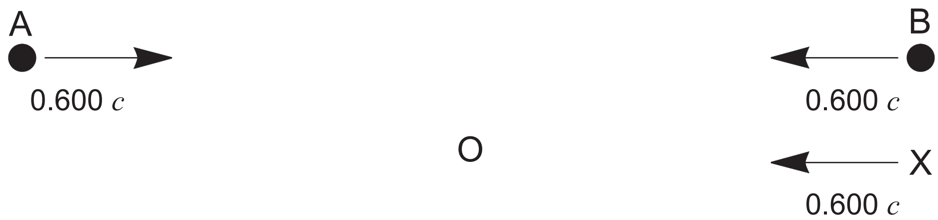

Figure 2: Observer X is now shown.

(c) Using the formulas for relativistic velocity addition and relativistic momentum, determine the momentum of the system before the collision, as determined by X. Express your answer in terms of m and c, the speed of light. (5 marks)

Answer ________________ mc

(d) With the use of a calculation, show that your answer in part (c) is the same as the momentum of the system after the collision, as determined by X. (4 marks)

Question 19 **(10 marks)**

A group of students wanted to calculate the strength of the Earth's magnetic field in Perth. They set up a DC circuit with a section of the wire placed 50.0 mm above a compass.

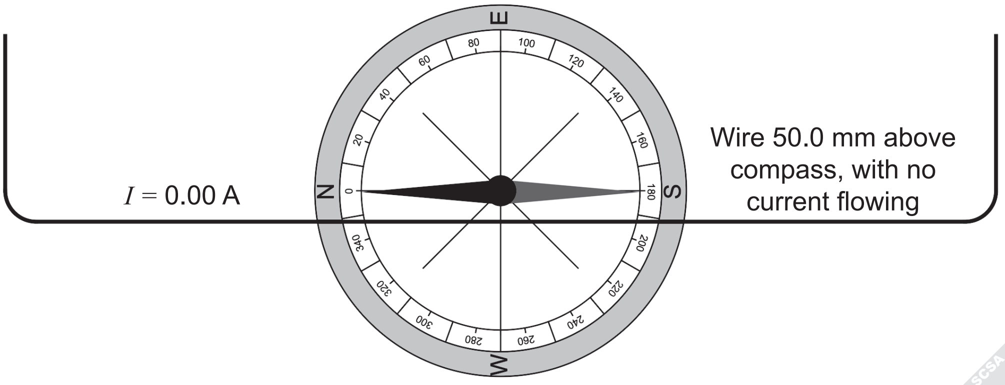

Figure 1

With no current running through the circuit, the compass lined up with the Earth's magnetic field as shown in Figure 1.

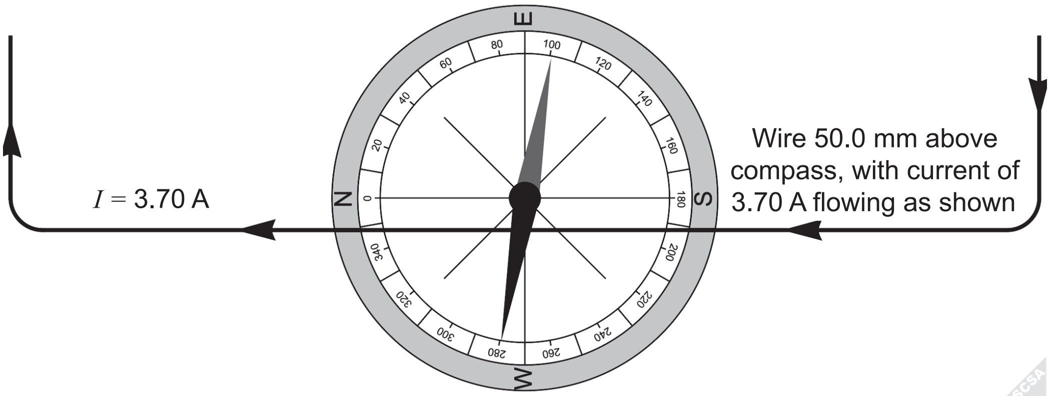

Figure 2

When they closed the switch, they saw the compass needle deflect at an angle of 80.0° to the wire as shown in Figure 2. The needle now pointed in the direction of the net magnetic field. The reading on the ammeter at this time was 3.70 A.

(a) Calculate the strength of the wire's magnetic field felt by the compass in the position described in Figure 2. (3 marks)

Answer ________________ T

(b) Calculate the strength of the horizontal component of the Earth's magnetic field. (4 marks)

Answer ________________ T

(c) The Earth's magnetic field is at an angle of 66.0° to its surface in Perth. This is called the 'angle of dip'. Use this information to calculate the overall strength of the Earth's magnetic field in Perth. (3 marks)

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Answer ________________ T

End of Section Two

Section Three: Comprehension **20% (38 Marks)**

This section has **two** questions. You must answer **both** questions. Write your answers in the spaces provided.

When calculating numerical answers, show your working or reasoning clearly. Give final answers to **three** significant figures and include appropriate units where applicable.

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Suggested working time: 40 minutes.

Question 20 **(20 marks)**

Restoring The Night Watch

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Rembrandt's *The Night Watch* was painted in 1642. But there is something odd about the name 'The Night Watch': it was not the name of the original painting. After it was restored, it became obvious that it was a daytime scene.

By the end of the 18th century, the painting had accumulated so many layers of varnish and dirt that it looked like the scene took place at night − and hence, it was misnamed 'The Night Watch'. The Rijksmuseum in Amsterdam carried out the largest research and restoration project ever. With the aid of X-ray fluorescence spectrometry, expensive paintings can be investigated harmlessly before restoration. This ensures sophisticated preservation of valuable art objects. It also allows the paintings to be restored securely in the buildings where the public can still enjoy them.

Depending on its energy, the X-ray beam penetrates into different depths of the painting's surface. This allows us to examine different layers of paint and even detect corrections made by Rembrandt without having to remove any paint. It is already known today that Rembrandt lengthened lances (spears) and changed the positioning of the people in the picture.

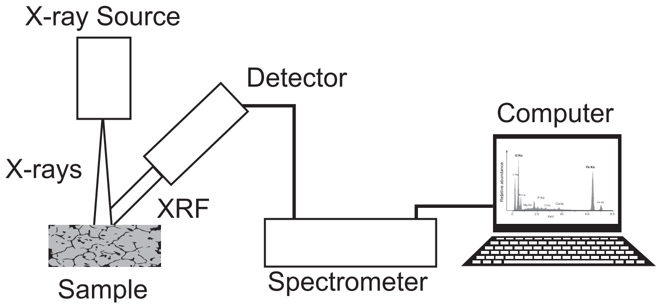

Figure 1: Schematic of process of X-ray fluorescence spectrometry

The spectrometer analyses the specific wavelengths of light given off by each sample of paint. It produces a printout similar to the one in Figure 2 showing the abundance of each wavelength emitted versus their energies.

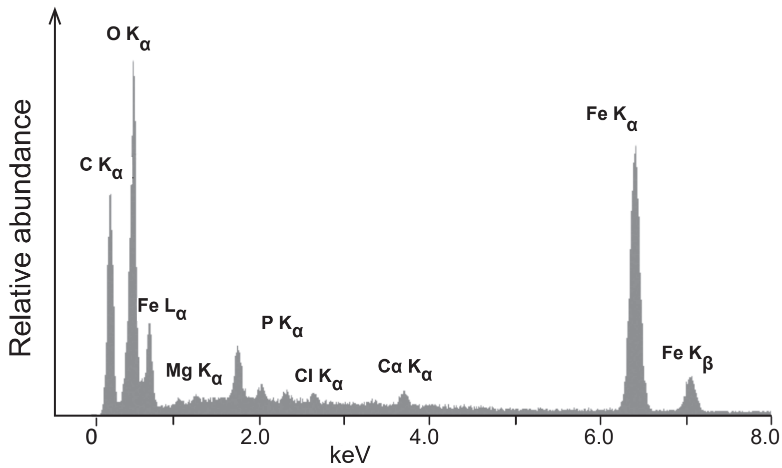

Figure 2: The relative abundance of energies of emitted photons

X-ray fluorescence analysis (XRF) is based on the detection of the fluorescence produced after the sample is bombarded with X-rays. Inner electrons are ejected by the incoming X-rays and then other electrons in higher energy shells cascade downward in smaller steps, emitting photons with specific wavelengths corresponding to the energy difference between shells. This fluorescence radiation is element-specific as the energy of each shell 'n' is given by:

$$E_n \propto \frac{Z^2}{n^2}$$

where Z is the charge on the nucleus, which is directly proportional to the number of protons in the nucleus. (For the K shell n = 1, for the L shell n = 2, and for the M shell n = 3.)

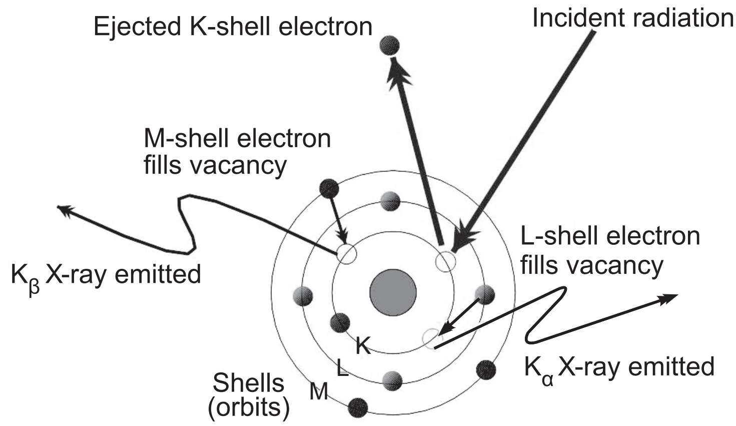

Figure 3: Electron transitions between K, L and M energy shells

Question 20 (continued)

The main spectral lines correspond to electron transitions to the K shell. Transitions from the L shell to K shell produce K_α photons and those from the M shell to K shell produce K_β photons. This process is described in Figure 3.

(a) List **two** properties of X-rays that make them suitable for X-ray fluorescence spectrometry. (2 marks)

One: ______________________

Two: ______________________

(b) Explain how we now know that Rembrandt's original painting had lances of different length and some of the people were in different positions. (2 marks)

(c) Give **two** advantages of using X-ray spectrometry to analyse old paintings. (2 marks)

One: ______________________

Two: ______________________

(d) Explain why the fluorescent radiation is element specific. (3 marks)

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(e) (i) Estimate the values of the M and L energy shells relative to the K shell for iron (Fe) displayed in Figure 2 and place them in the corresponding spaces below. (3 marks)

M ________________ eV

L ________________ eV

K 0 eV

(ii) Estimate the wavelength of the photon given off when an electron falls from the M shell to the L shell in an iron atom. (4 marks)

Answer __________________ m

(iii) To which part of the electromagnetic spectrum does this wavelength belong? (1 mark)

(f) How would the graph in Figure 2 change if the operators of the spectrometer increased the power of the X-ray beam while keeping the wavelength constant? Explain your answer.

(i) Change (1 mark)

(ii) Explanation (2 marks)

Question 21 **(18 marks)**

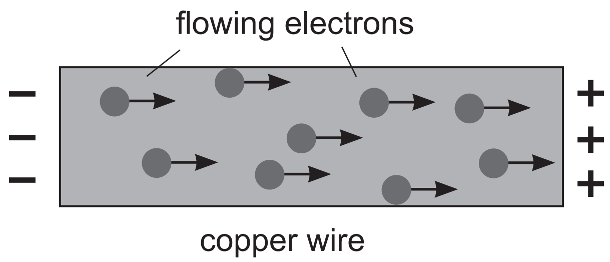
Drift velocity

When you turn on a light, it comes on as soon as the circuit is complete. The energy flowing in the circuit is transferred almost instantly. But how fast do the charged particles, which carry that energy, move? It turns out that they move extremely slowly. This velocity is called the drift velocity and it depends on several factors. The equation is given below:

$$v_D = \frac{I}{nAq}$$

where,

- I is the current flowing through the conductor, measured in amperes
- n is the electron density in m^{-3}
- A is the area of the cross-section of the conductor, measured in m^2
- v_D is the drift velocity of the electrons, measured in $m\ s^{-1}$
- q is the charge of an electron, measured in coulombs.



(a) Calculate the drift velocity of electrons if a current of 3.00 A is flowing in a copper wire with a cross-sectional area of 1.00 mm^2. (3 marks)

For copper, $n = 8.50 \times 10^{28}\ m^{-3}$.

Answer ____________________ $m\ s^{-1}$

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Another way of measuring drift velocity uses what is called the Hall Effect. This occurs when a current flows through a flat piece of metal placed in an external magnetic field. This is shown in the diagram below.

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The negatively charged particles experience a force due to the magnetic field and move to one side of the metal strip. This sets up a potential difference, and therefore an electric field, between the sides of the strip. This potential difference can be measured by a voltmeter (V_H). Dividing V_H by the width of the strip (w) will give us the strength of the electric field created:

$$E = \frac{V_H}{w}$$

If the strip is moved with the same velocity as the charge carriers but in the opposite direction, their relative velocity in the field is now zero; and therefore, there is no force placed upon them by the magnetic field. At this stage, the voltmeter would read 0 V. By measuring how fast the strip is moving, we can calculate drift velocity.

The magnetic force on the charged particles is:

$$F_M = qv_DB$$

where v_D is the drift velocity of the charge.

When the strip is not moving and the system reaches equilibrium, V_H remains constant and the force exerted on the charge carriers by the magnetic field (F_M) is equal to the force due to the electric field between the edges of the strip (F_E). By substitution, it can be shown that:

$$F_E = \frac{V_H q}{w}$$

Question 21 (continued)

(b) With reference to the text, explain why V_H reduces to zero when the strip is moved in the correct direction at the correct speed. (4 marks)

(c) Explain why increasing the magnitude of the magnetic field will increase V_H for a stationary strip when equilibrium is restored. (3 marks)

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(d) The article says: '*By substitution, it can be shown that:* $F_E = \frac{V_H q}{w}$'. Derive this equation from information supplied in the article. (2 marks)

(e) Calculate V_H if the dimensions of the copper strip are w = 3.00 cm and d = 0.100 cm, B = 3.50 T and I = 26.0 A. Use electrons as the charge carriers in your calculation. (6 marks)

For copper, $n = 8.50 \times 10^{28}$ m^{-3}.

Answer ______________ V

End of questions

Supplementary page

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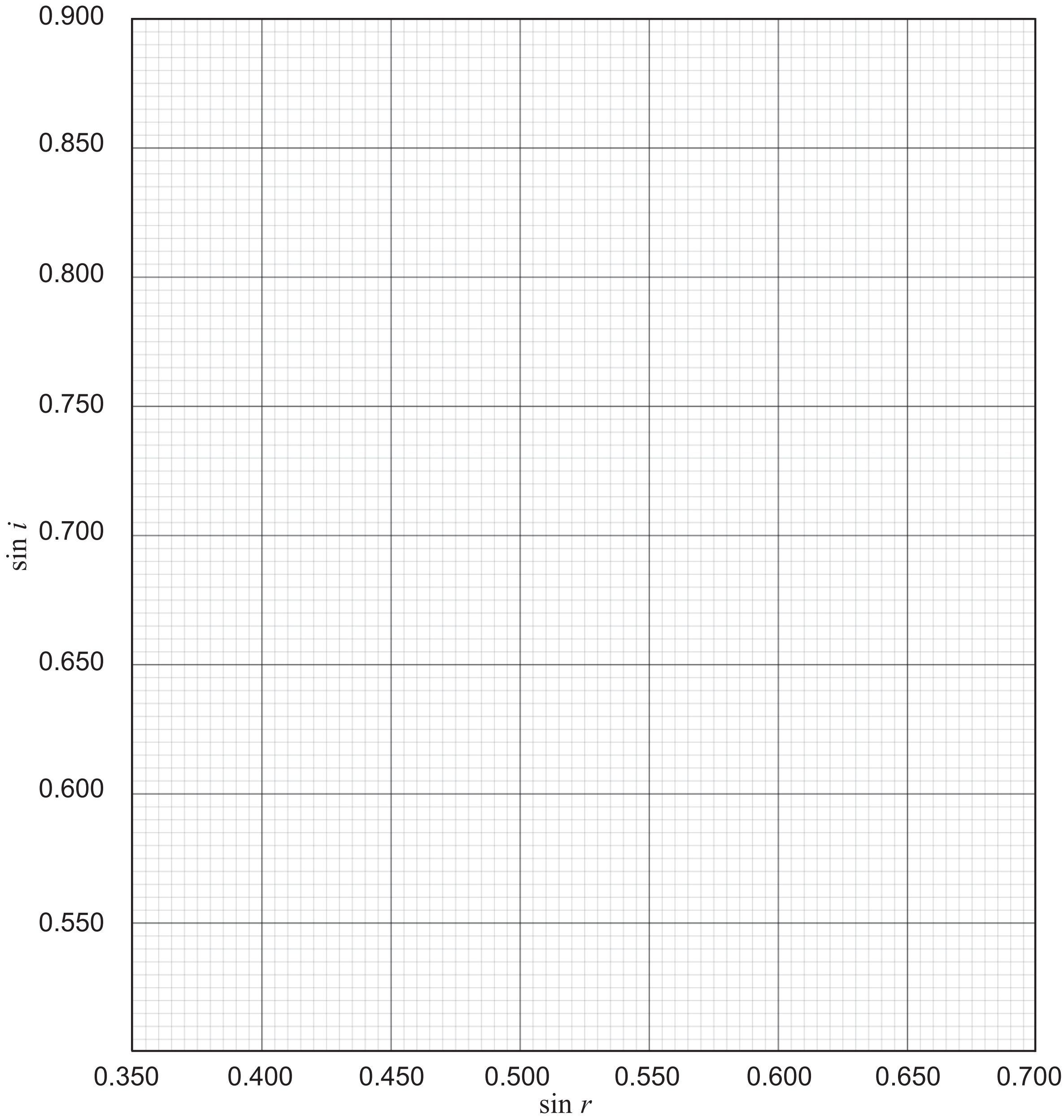
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ACKNOWLEDGEMENTS

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