Rossmoyne Senior High School

ATAR course examination, 2021

Question/Answer booklet

PHYSICS UNIT 3 AND 4

Student number: In figures

In words

Time allowed for this paper

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

Materials required/recommended for this paper

To be provides 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, eraser, ruler, highlighters.

Special items: up to three non-programmable calculators approved for use in the WACE examinations, 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.

Structure of this paper

Section	Number of Questions	Questions to be answered	Suggested working time (minutes)	Marks available	Percentage of exam
Section One Short Response	11	11	50	54	30
Section Two Problem Solving	7	7	90	90	50
Section Three Comprehension	2	2	40	36	20
			Total	180	100

Instructions to candidates

1. Write your answers in the spaces provided beneath each question. The value of each question (out of 180) is shown following each question.

2. Answers to questions involving calculations should be evaluated and given in decimal form. Final answers should be given up to a maximum of three significant figures and include appropriate units where applicable.

3. Questions containing the instruction "estimate" may give insufficient numerical data for their solution. Give final answers to a maximum of two significant figures and include appropriate units.

4. Despite an incorrect result, credit may be obtained for method and working providing these are clearly and legibly set out.

5. Questions containing specific instructions to "show working" should be answered with a complete, logical, clear sequence of reasoning showing how the final answer was arrived at; correct answers which do not show working will not be awarded full marks.

6. Supplementary pages for the use of planning/continuing your answer to a question have been 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.

7. Extra/spare graphs have also been provided at the end of this Question & Answer booklet.

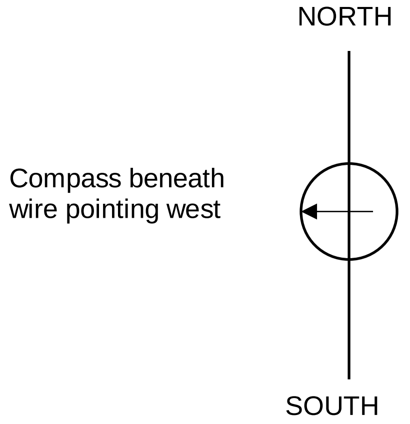
Section One: Short Response **30% (54 marks)**

This section has eleven (11) questions. Answer **all** questions. Write your answers in the spaces provided.

Suggested working time: 50 minutes.

Question 1 **(4 marks)**

In a Physics experiment, a group of students run a DC current through a horizontal wire aligned in a North-South direction. They measure the magnetic field strength 13.5 cm from the wire and its magnitude is 3.56×10^{-6} T. A compass is placed directly **below** the wire. When the current is flowing, it points to the west (see diagram below). You should ignore any effects of the Earth's magnetic field.



(a) State the direction in which the current will be flowing – North or South.

(1 mark)

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(b) Calculate the size of the current flowing in the wire.

(3 marks)

__________ A

Question 2 **(4 marks)**

The table below shows some properties of the six known quarks. All matter is made up of hadrons and leptons. Mesons are composed of a quark-antiquark pair.

NAME	SYMBOL	Charge (Q)	Baryon Number (B)	Strangeness (S)	Charm (c)	Bottomness (b)	Topness (t)
Up	u	$+\frac{2}{3}$ e	$\frac{1}{3}$	0	0	0	0
Down	d	$-\frac{1}{3}$ e	$\frac{1}{3}$	0	0	0	0
Strange	s	$-\frac{1}{3}$ e	$\frac{1}{3}$	-1	0	0	0
Charmed	c	$+\frac{2}{3}$ e	$\frac{1}{3}$	0	+1	0	0
Bottom	b	$-\frac{1}{3}$ e	$\frac{1}{3}$	0	0	-1	0
Top	t	$+\frac{2}{3}$ e	$\frac{1}{3}$	0	0	0	+1

(a) Give the quark composition of the following hadrons:

(i) The baryon lambda-zero Δ^0 which has Q = 0, B = 1, S = -1 and c = t = b = 0 (1 mark)

(ii) The meson pion-plus π^+ which has Q = +1, B = 0, S = 0 and c = t = b = 0 (1 mark)

(b) Give two (2) reasons, referring to the known rules involving quantum numbers, why the quark combination of ud is not possible.

(2 marks)

Question 3 **(5 marks)**

The planet Uranus has a mass of 8.68 x 10^{25} kg and is circled by 27 known moons. One of these is called Portia, which has the following characteristics:

Mass	**1.70 x 10^{18} kg**
Orbital period	**0.513 days**
Mean Diameter	**135.2 km**
Orbital Speed	**9.37 km s^{-1}**

An object launched vertically upwards from the surface of the Earth would reach a much lower maximum height than if it was launched in the same way on Portia.

(a) Calculate the gravitational field strength on the surface of Portia.

(2 marks)

_______________ N kg^{-1}

(b) By comparing your answer to part (a) with the gravitational field strength of the Earth, explain – using relevant equations of motion – why an object launched vertically upwards on Portia will reach a higher vertical displacement than when launched the same way on Earth.

(3 marks)

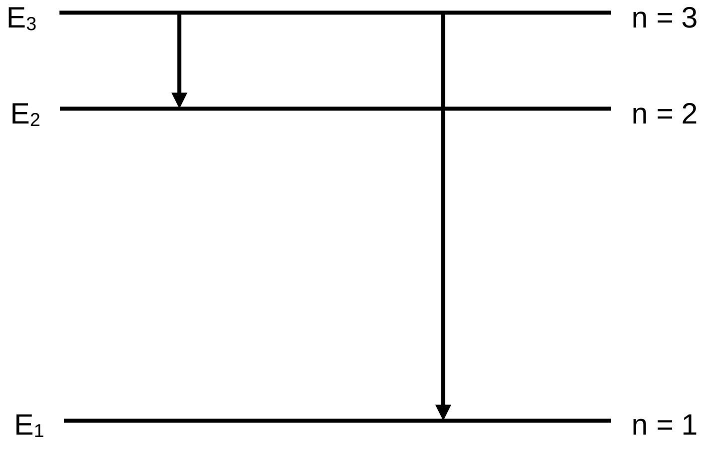
Question 4 **(4 marks)**

In a particular photoelectric experiment, a stopping voltage of 2.10 V is measured when ultraviolet light of wavelength 292 nm is incident upon the metal. Calculate the work function of the metal in eV.

____________________ eV

Question 5 **(4 marks)**

The diagram below shows the first three energy levels for an unknown atom.



Two downward electron transitions are shown: n = 3 to n = 2; and n = 3 to n = 1.

The transition from n = 3 to n = 2 causes a visible light photon to be emitted – the other transition shown does not. Name a region in the electromagnetic spectrum that the photon emitted by the transition from n = 3 to n = 1 is likely to come from. Explain your choice.

Question 6 **(7 marks)**

TV signal is broadcast in Australia in a band of frequencies from 90.0 MHz and 108.0 MHz. When the TV signal travels into the upper regions of the atmosphere, its speed changes, are reflected back down to the earth's surface and its electric field becomes aligned to the horizontal plane. The antenna, as shown in the diagram below can then receive the TV signal by interacting with the electric field of the signal. These EM wavelengths are larger than other regions of the EM spectrum which enables the wave to pass around large objects as it is broadcast.

(a) State one light phenomena described in the passage above and state which model of light this phenomenon supports. (1 mark)

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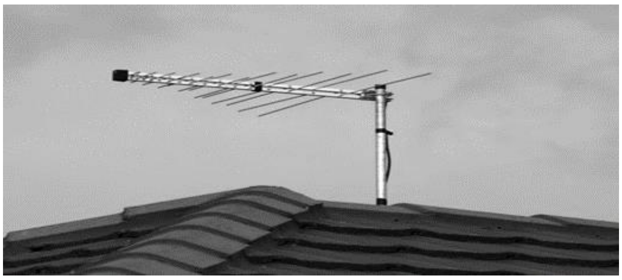
Receiving antenna for these TV signals must be installed horizontally and have a range of lengths in order to best receive the signals from different frequencies. Typically, the antenna length must be equal to half of the wavelength it is receiving.



(b) Explain why the antenna must be installed horizontally. (2 marks)

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(c) Calculate the maximum and minimum ideal lengths of the TV aerial to be used in Australia. (4 marks)

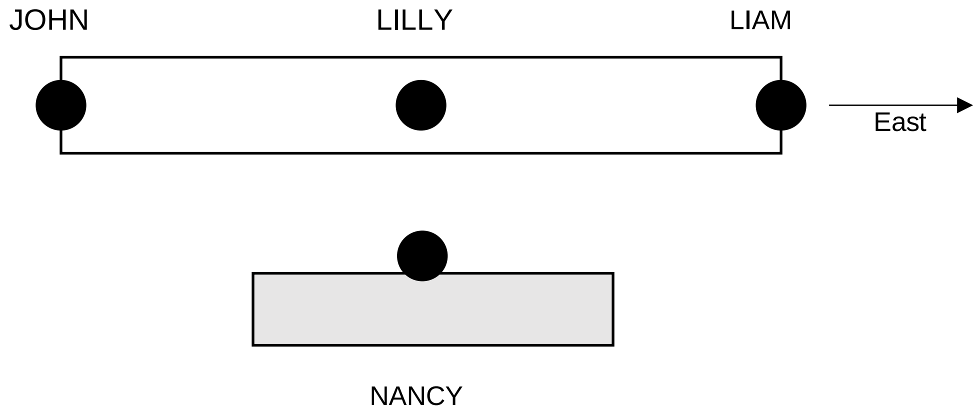
Max: _______________ m Min: _______________ m

Question 7 **(5 marks)**

The diagram below shows Lilly in a futuristic train carriage which is travelling with a constant relativistic speed, in an easterly direction, in a straight line.

Lilly is halfway between two people - John and Liam - who are at opposite ends of the carriage.

Nancy is standing on a platform as the train travels past. At the instant that Lilly and Nancy are directly opposite each other, Nancy sees both John and Liam strike matches simultaneously.



(a) Circle the option (A-D) that best describes how Nancy would expect Lilly to see these two events.

A Lilly sees the light from John first.
B Lilly sees the light from Liam first.
C Lilly sees the light from both simultaneously.
D Lilly will only ever see the light from Liam.

(1 marks)

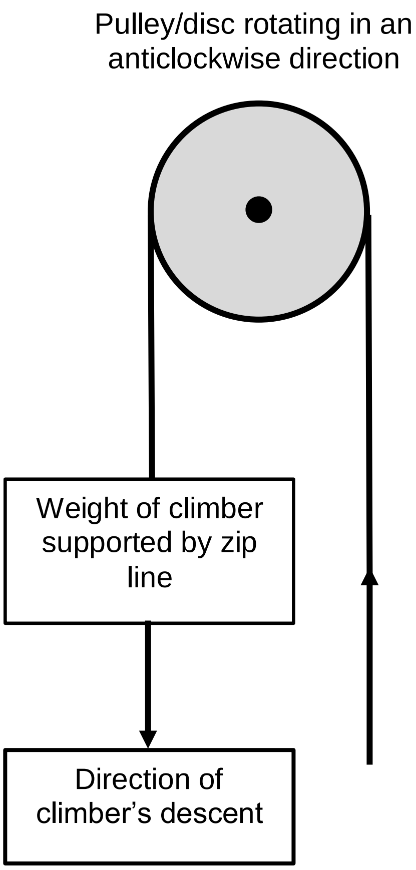
(b) Lilly measures the carriage she is travelling in to be 20.0 m long. Nancy measures the platform she is standing on to be 10.0 m long. The train rushes past at such a high speed that Nancy sees the carriage and the platform to be the same length. Calculate the speed (in m s^{-1}) at which the train is moving.

(4 marks)

__________ m s^{-1}

Question 8 **(5 marks)**

Rock climbers often need assistance to descend at a safe speed from great heights. A braking system can be applied to create this safe speed. One zip line system is illustrated below.



The rotating pulley is an aluminium disc. When the climber is descending, they are able to switch on electromagnets situated alongside the rotating disc which creates the 'brakes'. The current supplied to the electromagnets can be varied by the climber to control their speed.

Explain how this braking system works and how the current can control the climber speed.

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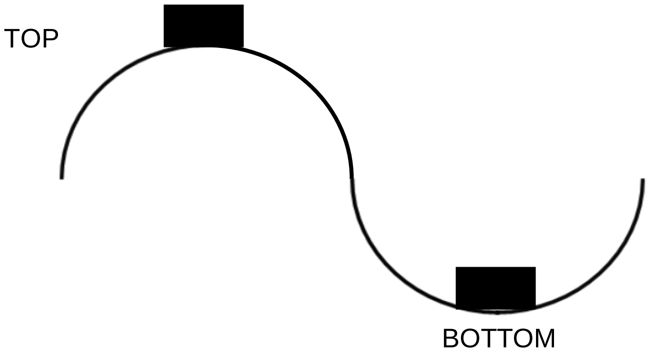
Question 9 **(6 marks)**

One of the thrilling parts of a rollercoaster ride is when the passengers travel over the top and through the bottom of a vertical circular path. Apart from the high speeds that can be reached, the other interesting feature is the change in 'apparent weight' experienced by the occupants of the ride at these points. [NOTE: at all locations, the carriage carrying the occupants is above the track]



(a) Compare and explain the changes in 'apparent weight' experienced by the occupants at the top and bottom of the vertical circular path as they travel through these points. Use appropriate mathematical expressions in your answer.

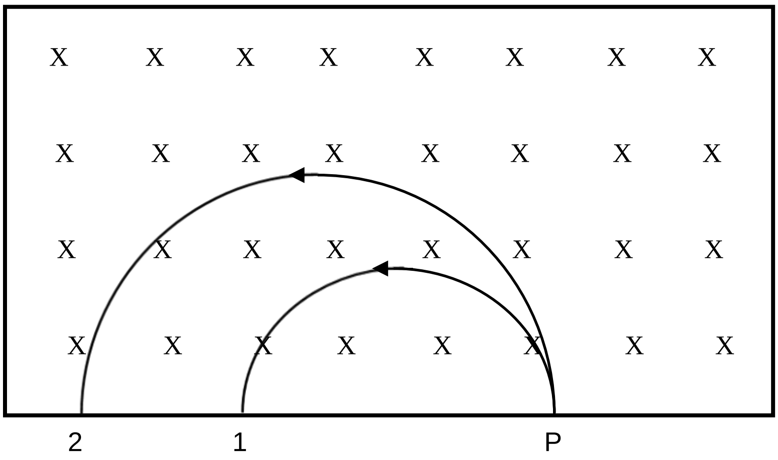
(4 marks)

(b) In a 'loop-the-loop' design, the rollercoaster can travel upside down at the top of the vertical circle. Obviously, the occupants are strapped in very securely. However, it is possible for them to travel upside down without falling out of the rollercoaster. Explain, with reference to the forces involved, the minimum conditions that would allow this to occur.

(2 marks)

Question 10 **(6 marks)**

Two charged particles of the same mass and with the same speed enter vacuum chamber at point ‘P’ and follow the paths (‘1’ and ‘2’) shown. The magnetic field in the vacuum chamber is uniform, perpendicular to and into the page.



(a) State the type of charge (positive/negative) on each particle.

(1 mark)

(b) Which path represents the particle with the largest charge? Explain.

(2 marks)

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(c) If the chamber was filled with air instead of a vacuum, describe the shape of the paths and explain your answer.

(3 marks)

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Question 11 **(4 marks)**

A group of Physics students constructed an AC generator out of a single rectangular coil, a reasonably strong horseshoe magnet and other materials lying round the house.

Once they started to rotate the coil at 3.00 Hz, they measured an RMS voltage output of 0.0249 mV.

The coil has dimensions of 1.50 cm x 2.50 cm. Calculate the magnetic flux density produced by the horseshoe magnet in the area within the rotating coil.

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END OF SECTION ONE

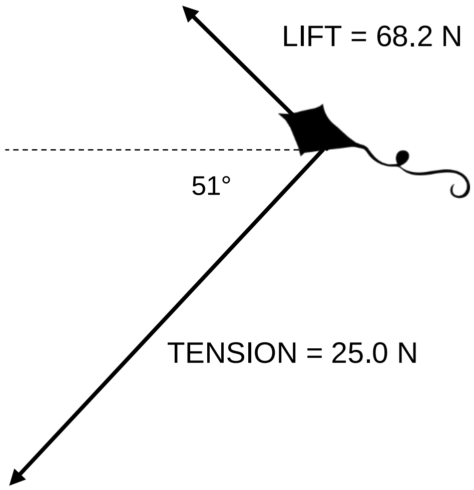
Section Two: Problem Solving **50% (90 marks)**

This section contains seven (7) questions. Answer **all** questions. Answer the questions in the space provided.

Suggested working time is 90 minutes.

Question 12 **(9 marks)**

A boy is flying a kite and makes it trace out a horizontal circular path. He steers the kite by applying a force to it via tension in a connecting cable. The situation is illustrated in the diagrams below (diagrams not to scale).



At a particular instant, as the kite traces out its circular path, the tension in the cable is 25.0 N. The kite experiences a lift force equal to 68.2 N which acts normal to the tension force, as shown.

(a) Calculate the mass of the kite.

(5 marks)

____________ kg

(b) If the kite is travelling in a horizontal circular path with a radius of 15.6 m, calculate the average circular speed achieved.
[If you were unable to calculate an answer for part (a), use a value of 2.50 kg]

(4 marks)

____________ m s^{-1}

Question 13 **(15 marks)**

Some Physics students decide to calculate an experimental value for Planck's constant (h) using a light emitting diode (LED).

LED's are semi-conductors that emit electromagnetic radiation in optical and near-optical wavelengths when a voltage is applied to them. LED's only emit this light when the voltage is above a minimum threshold value. The light produced is monochromatic (ie – has a very specific wavelength range). Each photon emitted has an energy equal to the energy lost by the electrons in the LED.

The students create a circuit that allows them to measure the threshold voltage (V_0) applied to an LED and the maximum wavelength (λ) of the emitted photons with a spectroscope. The students use LED's of different colours (ie – different maximum wavelengths) and measure their corresponding values for V_0.

(a) Using formulae from the Formulae and Data Booklet, show that the relationship between the threshold voltage (V_0) and the maximum wavelength (λ) for an LED is given by:

$$\mathbf{V_0 = \frac{hc}{q_e \lambda}}$$

$$\textbf{where h = Planck's constant; c = speed of light; } \mathbf{q_e} \textbf{ = charge on an electron.}$$

(2 marks)

The students perform the experiment using four (4) different LED's and gather the following results.

LED colour	V_o (V)	λ (nm)	1/λ (x 10^6 m^{-1})
Infrared	**1.24**	**1000**	**1.00**
Red	**1.79**	**695**	
Yellow	**1.88**	**660**	**1.52**
Green	**1.97**	**630**	**1.59**

(b) Complete the table by filling in the missing value in the '1/λ' column.

(1 mark)

(c) On the graph paper provided on the next page, plot a graph of 'V_o' against '1/λ'. Place '1/λ' on the horizontal axis. Draw a line of best fit for the data.

(4 marks)

(d) Calculate the slope of your line of best fit. Include units in your answer.

(4 marks)

Slope: ____________ Units: _____________

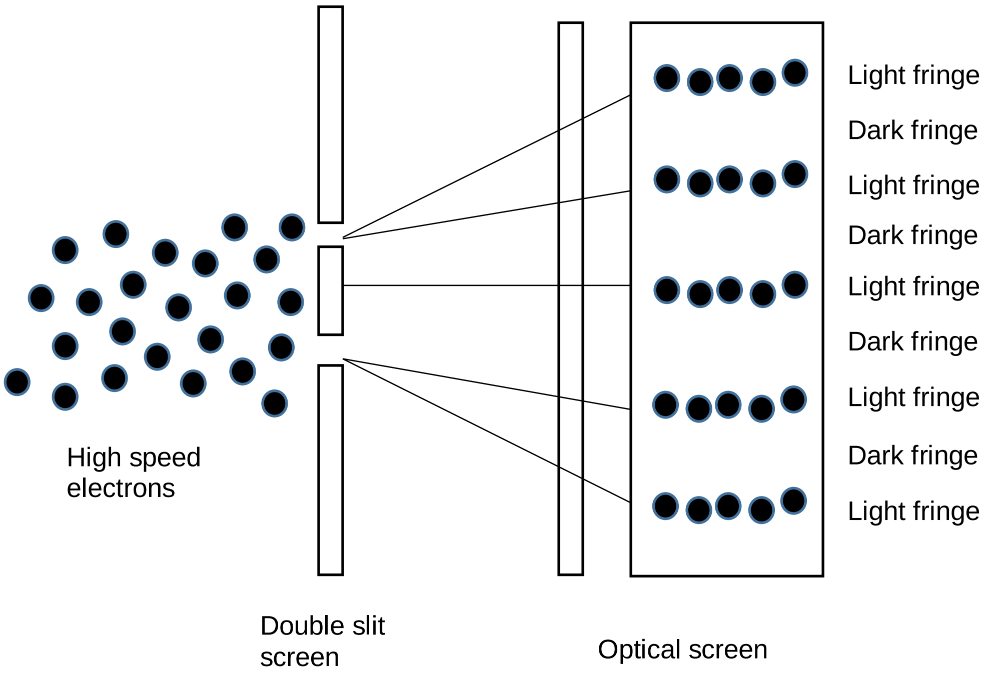
(e) Use the slope from part (d) to calculate an experimental value for Planck's constant (h).

(4 marks)

Planck's Constant (h): ___________

Question 14 **(12 marks)**

Some students perform the ‘double slit’ experiment using high speed electrons. The electrons pass through a barrier with two openings and are detected when they collide with an optical screen. The optical screen exposes a pattern of dark and light fringes. This experiment is shown in the diagram below.



The electrons are acted on by an accelerating electric potential and arrive at the screen with a speed of 2.50×10^5 m s^{-1}.

(a) Calculate the magnitude (in Volts) of the accelerating electric potential. Show working. Ignore relativistic effects.

(4 marks)

______________ V

(b) State what the experiment demonstrated about the behaviour of the electrons.

(1 mark)

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(c) Explain how the dark and light fringes are formed.

(4 marks)

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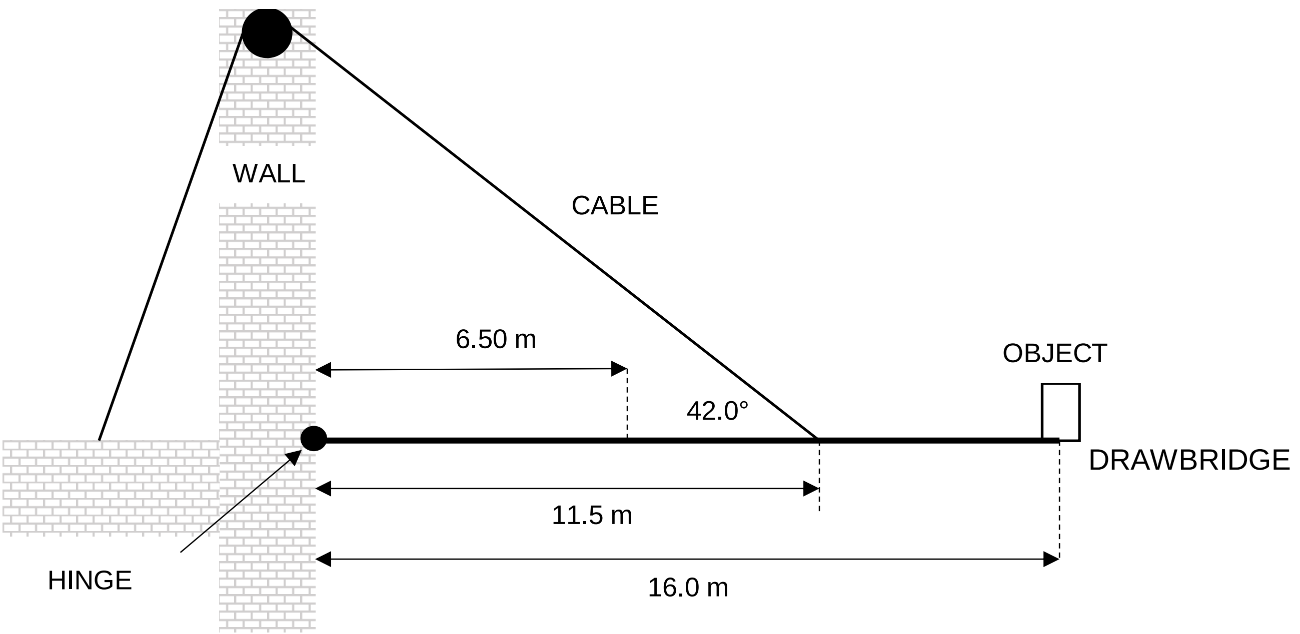
(d) Calculate the de Broglie wavelength for these electrons.

(3 marks)

______________ m

Question 15 **(17 marks)**

The diagram below shows a horizontal drawbridge which is supported by a cable and pulley system. This system is used to raise and lower the drawbridge when required.



The drawbridge has a mass of 250.0 kg is and 16.0 m long. Its centre of mass is located 6.50 m from the hinge as shown. At the instant that it is held in the horizontal position shown, a 70.0 kg object is placed right at the end of the drawbridge. The cable is attached to the drawbridge 11.5 m from the hinge at an angle of 42.0° to the horizontal.

(a) Draw a free-body diagram to represent the drawbridge when it is in the horizontal position shown. Include all important labels, dimensions and angles.

(4 marks)

(b) Calculate the tension (T) in the cable when the drawbridge is in this horizontal position.

(4 marks)

_______________ N

(c) Hence, calculate the force (magnitude and direction) the wall exerts on the drawbridge at point ‘P’.

(5 marks)

________________ N Direction: ____________

(d) The drawbridge is elevated into a position where the object just begins to slide towards the hinge. If the maximum frictional force experienced between the object and the drawbridge is 320 N, calculate the angle to the horizontal to which the drawbridge has been elevated.

(4 marks)

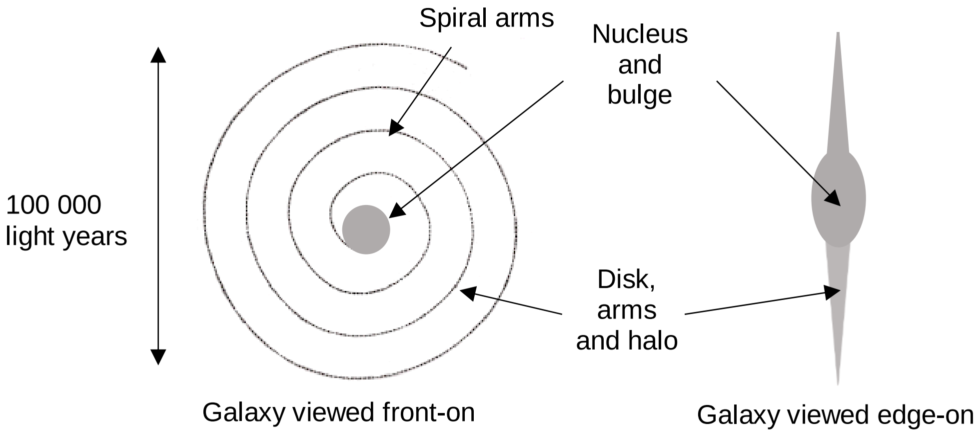
____________ °

Question 16 **(16 marks)**

The Milky Way Galaxy is our home in the Universe. It has the structure of a typical spiral galaxy and consists of six separate parts:

(i) A nucleus (which contains a massive black hole); (ii) a central bulge; (iii) a disk (both thick and thin); (iv) spiral arms; (v) a spherical component; and (vi) a massive halo.

The diagrams below show simplified diagrams of what we think the Milky Way Galaxy looks like.



Astronomers have made observations that confirm the Milky Way's structure. They have also confirmed:

- the spiral arms of the galaxy are rotating around the central bulge and nucleus;
- the mass of the entire galaxy.

Our own Sun orbits the centre of the Milky Way on one of the spiral arms with an orbital radius of 2.60 x 10^4 light years and period of 225 million years. The mass of the Milky Way can be calculated by observing the motion of satellites (stars) like our Sun as they orbit the central bulge.

(a) Using the orbital data for our Sun, show that the mass of the Milky Way is about 1×10^{11} solar masses (1 solar mass = mass of Sun).

(5 marks)

____________________ solar masses

(b) Using formulae from the Formulae and Data Booklet, derive the expression that shows a stars orbital speed (v) with an orbital radius (r) as it orbits the Milky Way's centre of mass (M) is given by $v = \sqrt{\frac{GM}{r}}$.

(3 marks)

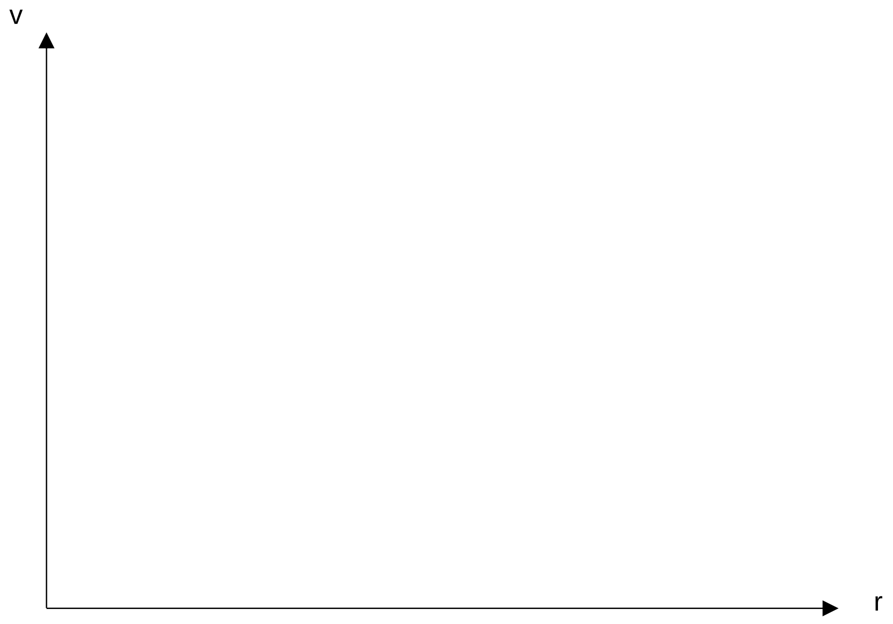
(c) Use this expression to calculate the orbital speed of the Sun.

(2 marks)

________________ m s^{-1}

(d) On the axes below, sketch a graph that shows how the orbital speed (v) of stars in the Milky Way should vary with their orbital radius (r).There is no need to provide any values on the axes.

(2 marks)

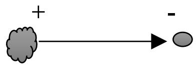


(e) It is predicted that, from the outer edge of the galaxy, stars with a small orbital radius would be observed to produce a repeating pattern of red and blue shifted light throughout as they orbit and that the magnitude of the shift increases with decreasing orbital radius. Explain these two observations.

(4 marks)

Question 17 **(11 marks)**

A radioisotope of rest mass 1.40 x 10^{-29} kg is travelling away at 0.400 c to a stationary observer when it ejects a beta particle of rest mass 9.11 x10^{-31} kg. The beta particle is observed from the stationary observer to be travelling at 0.950 c away from him. Upon emission, the radioisotope becomes positively charged. Ignore any effects of recoil in this question



(a) Calculate the emission speed of the beta particle from the radioisotope's frame of reference.

(3 marks)

________________ c

(b) Calculate the momentum of the beta particle as measured from the stationary observer.

(3 marks)

________________ kg m s^{-1}

The radioisotope is measured by the stationary observer to move from point A to a stationary detector at point B to be 0.120 µs.

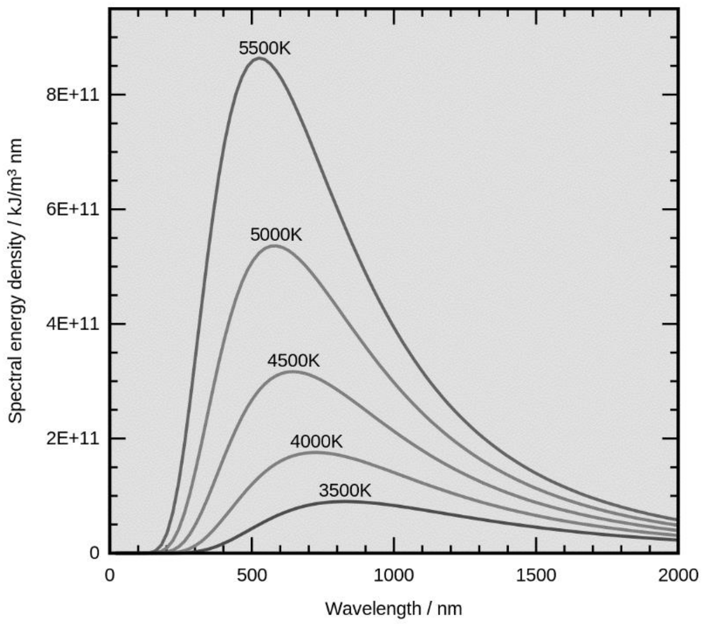
(c) Calculate the distance that the radioisotope travels from its frame of reference.

(5 marks)

______________ m

Question 18 **(10 marks)**

When the temperature of a blackbody radiator increases, the overall radiated energy increases and the peak of the radiation curve moves to shorter wavelengths. When the maximum wavelength is evaluated from the blackbody curves, the product of the peak wavelength and the temperature is found to be a constant. This equation is known as Wein's Law:



$$T = \frac{B}{\lambda}$$

Where:

T = Temperature (K)

λ = peak wavelength (m)

B = Wein's constant

(a) Using the blackbody curve of the 5000 K radiator, provide a calculation of Wein's constant, including units.

(4 marks)

Wein's constant: ____________________ Units: _____________

(b) Hence, calculate the peak wavelength of the sun's blackbody curve, whose surface temperature is 5800 K. If you could not obtain an answer to part (a), you may assume a value of 3.5×10^{-3}.

(3 marks)

__________________ m

The intensity "I" of a blackbody is the sum total of the energy released by that body across all wavelengths, per unit surface area per unit time ($J\ m^{-2}\ s^{-1}$). The intensity of a black body can be calculated using the Stefan-Boltzmann Law:

$$I = \sigma T^4$$

Where T = Surface temperature (K)
σ = Stefan-Boltzmann constant of $5.67 \times 10^{-8}\ W\ m^{-2}\ K^{-4}$.

(c) Calculate the total power ($J\ s^{-1}$ or W) output of the sun whose surface temperature is 5800 K. Note: the surface area of the sun can be calculated using the formula $SA = 4\pi r^2$ and intensity, (power per unit area) can be expressed as I = P / A.

(3 marks)

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END OF SECTION TWO

Section Three: Comprehension **20% (36 marks)**

This section has two (2) questions. Answer **both** questions. Answer the questions in the spaces provided.

Suggested working time: 40 minutes.

Question 19 **(18 marks)**

How Should You Kick a Football to Achieve the Greatest Distance?

Physics has the answer – as always - at least in an 'ideal setting'

In any AFL football game, two teams are pitted against each other in the pursuit of glory. It turns out that they both have a common foe they need to defeat which is always trying to pull them (and the football) down – the force of gravity. The Earth's gravitational pull is constantly acting downwards on players and the football itself – preventing it from sailing through the goal posts from extra-long distances, or from hanging in the air for eternity.

Gravity is constant, so football players learn how to instinctively account for its effects when kicking the football around the field. They learn very quickly that a football, once kicked or handpassed, follows a parabolic path - a path that is essentially a symmetrical arc which eventually results in the ball landing back on the ground.

(In reality, the football's path is NOT a perfectly parabolic path; this is because its path is not only affected by gravity, but also by air resistance - which is created by drag in the air and even wind.)

The properties of parabolas are well understood by Physicists and Mathematicians (and even footballers!). For example, it can be shown mathematically that the maximum horizontal distance (s_h) achieved by a football after it has been kicked into the air will be equal to:

$$\mathbf{s_h = \frac{v^2}{g} \times \sin 2\theta}$$

where '*v*' is the projectile's initial speed; '*g*' is the acceleration toward Earth due to gravity (9.80 m s^{-2}); and '*θ*' is the angle to the horizontal at which the projectile is launched. In this case, it is assumed that the football is returning to the same height from which it is launched.

In this equation, a couple of the variables are pretty much fixed. The acceleration due to gravity '*g*' is obviously constant no matter how the ball is kicked.

In addition to this, if a footballer is trying to kick a football as far as they possibly can, they will launch it with a maximum launch speed '*v*' – which, in turn, simply depends on how hard they can kick the football.

The only decision, therefore, a footballer has to make when kicking a football to maximise horizontal distance is the launch angle '*θ*' at which the football is kicked. The equation above shows us that the horizontal distance travelled by the ball will be a maximum when *sin 2θ* is at its greatest value. So, a football will achieve its greatest horizontal distance when it is launched at an angle of 45° to the horizontal. Again, it is assumed that the football is returning to the same height from which it is launched.

Part of the kicking strategy in football is not only to kick the football as far as possible, but to control the flight time (or 'hang time') for the ball. A player may need to kick over another (tall) player; vary the time it takes for the football to reach another point on the ground; or kick it a shorter distance with a particular height.

The maximum height (s_v) achieved by a kicked football is given by:

$$\mathbf{s_v = \frac{v^2}{2g} \times (\sin\theta)^2}$$

Like before, *'v' and* 'g' are fixed values for a given type of kick.

From this equation, it can be seen that to achieve maximum height (s_v) a player needs to produce a launch angle of $\theta = 90°$. In other words, the ball needs to be kicked vertically upwards – a rare kick in football without much strategic value.

(a) The article states: "… a football, once kicked or handpassed, follows a parabolic path".

Assume the football is launched and lands at the same vertical height. By examining important aspects of a projectile's path, explain why a parabolic path is followed by the football.

[Note – a projectile's path is an inverted parabola which is symmetrical around the maximum height achieved by the projectile]

(4 marks)

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(b) "In reality, the football's path is NOT a perfectly parabolic path; this is because its path is not only affected by gravity, but also by air resistance - which is created by drag in the air and even wind."

(i) In the table below, state how the following aspects of a projectile's path would change from an 'ideal situation' when air resistance is taken into account.

(2 marks)

RANGE	
MAXIMUM HEIGHT	

(ii) Let the time taken for the football to travel from the ground **to maximum height be 't_{UP}'**.

Let the time taken for the football to travel from maximum height **to the ground be 't_{DOWN}'.**

When air resistance is ignored, these two values are the same (ie – $t_{UP} = t_{DOWN}$).

Compare these two values when **air resistance is taken into account**. Explain any differences between these values. As part of your answer, consider how gravity's effects would be affected by air resistance.

(3 marks)

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(c) If air resistance is ignored, for a projectile launched at an angle of ‘θ’ to the horizontal and with a speed of ‘v’, the horizontal and vertical components of the launch velocity are given by:

$$\mathbf{v_h = v\ \cos\theta \quad and \quad v_v = v\ \sin\theta}$$

Use these expressions - and appropriate formulae from the Formulae and Data Booklet – to show that for a projectile that is launched and lands at the same height, the maximum horizontal distance achieved will be:

$$\mathbf{s_h = \frac{v^2}{g} \times \sin 2\theta}$$

NOTE: you may find the following trigonometric identity useful in the solution of this question:

$$\mathbf{\sin 2\theta = 2\ \sin\theta\ \cos\theta}$$

(4 marks)

(d) A football is kicked with a velocity of 15 m s^{-1} at angle of 35° to the horizontal. Calculate the maximum horizontal distance achieved by the football if air resistance is ignored.

(2 marks)

______________ m

(e) A football is kicked with a velocity of 14 m s^{-1} and achieves a maximum height of 7.00m. Calculate the angle 'θ' at which the football is launched. Ignore air resistance.

(3 marks)

______________ °

Question 20 **(18 marks)**

The Bubble Chamber

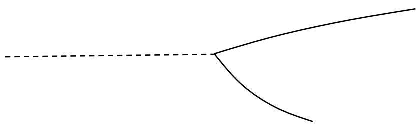
Since the early 1900s, the challenge faced by particle physicists was to detect and identify the myriad of particles that were being produced by high energy particle accelerators. The cyclotron was invented in 1930s and the LINAC around 10 years later. While the energies of the parent particles were known, very little was known about what was produced at the end of the beam. Indeed, in the first 20 years of these machines, they were crudely used as medical accelerators to blast subjects with high energy charged particles to treat localised tumours. The advent of the Bubble Chamber, first produced in 1952, changed all this; rapidly accelerating the development of the field of particle physics and what we currently accept as "The Standard Model".

Bubble Chambers are made by filling a large cylinder with a liquid (usually hydrogen) maintained at just below its boiling point. As particles enter the chamber, a piston suddenly decreases its pressure, and the liquid enters into a superheated, metastable phase. Charged particles moving through the superheated fluid create an ionisation track, around which the liquid vaporizes, forming microscopic bubbles. Bubble density around a track is proportional to the charged particle's energy loss. The bubbles grow in size as the chamber expands, until they are large enough to be seen or photographed. A useful benefit of using liquid hydrogen is that not only is the hydrogen used as the imaging medium, but it is also a very simple target; containing one proton and one electron. Being in its liquid state, rather than gaseous, it also greatly increases the probability of a particle interaction.

The entire chamber is subject to a constant magnetic field. It acts on charged particles through the Lorentz force and causes them to travel in helical paths whose radii are determined by the particles' charge-to-mass ratios and their velocities. Because the magnitude of the charge of all known, charged, long-lived subatomic particles is the same as that of an electron, their radius of curvature must be proportional to their momentum. Thus, by measuring a particle's radius of curvature, its momentum can be determined along with its rest mass, velocity and kinetic energy.

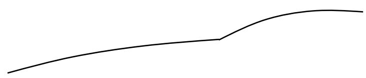
There are a few important bubble track shapes that have enabled physicists to solve the puzzles that particle interactions create.

A V-shaped track "vee" indicates a neutral particle decaying or interacting with a target nucleus to produce two oppositely charged particles. The dashed line in the diagram represents the path of a neutral particle and is not visible in a bubble chamber. The tip of the vee indicates where a decay has occurred to produce the charged particles.



A helical spiral of decreasing radius or "death-spiral" indicates a charged particle of low momentum not interacting with any other particle. These are nearly always electrons if produced on their own and eventual lose all of their kinetic energy due to ionizing liquid hydrogen and *bremsstrahlung*.

A kink in the track can indicate another particle interaction or the decay of a charged particle into another charged particle of the same sign but with a lower momentum. (Some momentum will be carried off by one or more neutral particles.)



(a) Explain why liquid hydrogen is used to detect particles, rather than gaseous hydrogen. (3 marks)

(b) Explain, making reference to relevant equations, how a death spiral indicates an electron of low momentum continuing to lose kinetic energy. (3 marks)

There are often many, unimportant background tracks produced during the production of an image. The figures on the following page show an important interaction; a pion (π^-) entering from the left, striking a proton and decaying into two neutral particles which also ultimately decay.

(c) Explain why, if one of the particles created from the proton-pion interaction is neutral, the other particle that is created must also be neutral.

(3 marks)

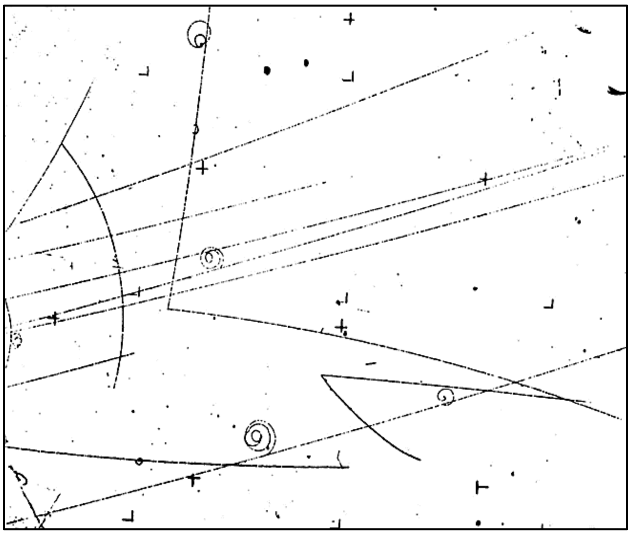


Figure 1:
Original image of pion beam

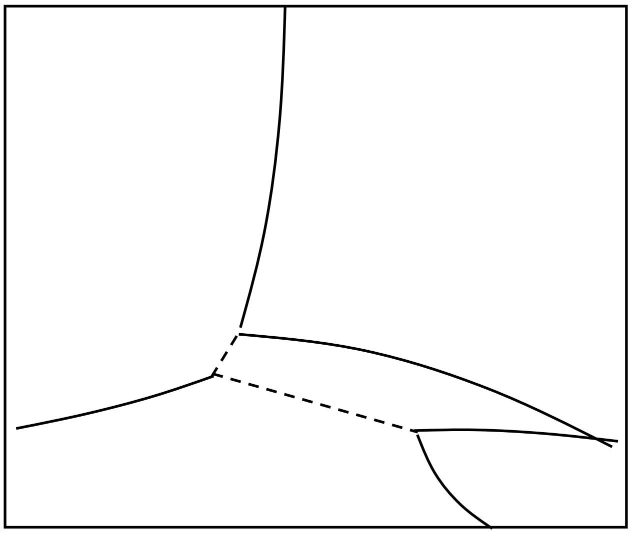


Figure 2:
Important interactions from Figure 1.

(d) Given that the death spirals in Figure 1 are created by electrons entering from the left, state and explain the direction of the magnetic field in the bubble chamber. (3 marks)

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(e) Circle two (2) areas on figure 2 where a neutral particle has decayed. (2 marks)

By analysing the initial momentum of the pion and measuring the angles that the neutral particles are deflected, it is possible to determine the momentum and hence energy and velocity of the neutral particles. In an image, a neutral particle was known to have a total energy of 232 MeV and a rest mass of 180 MeV/c^2. It is observed to exist for a distance of 5.80 cm before decaying into a visible vee.

(f) Show that the speed of the particle is 1.89 $\times 10^8$ m s^{-1}.

(4 marks)

END OF EXAMINATION

EXTRA GRAPH PAPER

Extra Working Space

Extra Working Space

Extra Working Space

Questions	Marker	Sub Total
1-4	TW	/17
5-8	SH	/21
9-13	MS	/40
14	TW	/12
15-17	DP	/44
18	SH	/10
19	MS	/18
20	DP	/18
Total:		**/180**