IB DIPLOMA PROGRAMME
PROGRAMME DU DIPLÔME DU BI
PROGRAMA DEL DIPLOMA DEL BI

PHYSICS
STANDARD LEVEL
PAPER 3

Friday 3 May 2002 (morning)

1 hour

Name

Number

INSTRUCTIONS TO CANDIDATES

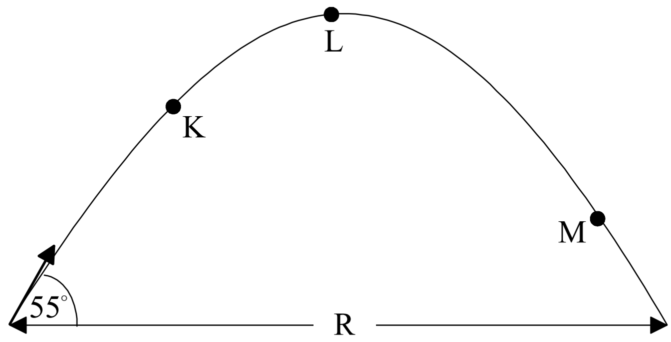
- Write your candidate name and number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Answer all of the questions from two of the Options in the spaces provided.
- At the end of the examination, indicate the letters of the Options answered in the boxes below.

OPTIONS ANSWERED	EXAMINER	TEAM LEADER	IBCA
	/20	/20	/20
	/20	/20	/20
	TOTAL /40	TOTAL /40	TOTAL /40

OPTION A — MECHANICS EXTENSION

A1. This question is about particle trajectories.

The diagram below shows a trajectory for a projectile launched at an angle of 55° to the horizontal with a speed of $20\,\mathrm{m\,s^{-1}}$. Air drag has been neglected. The arrow represents the initial velocity vector for the projectile. The distance marked R is the range of the trajectory.



(a) The points K, L and M label the position of the projectile for different times in its trajectory. On the above diagram, draw the horizontal and vertical components of the projectile's velocity at these points. *[3]*

(b) Calculate the time taken for the projectile to reach its maximum height. *[3]*

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(c) Calculate the range R of this projectile. *[3]*

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A2. This question is about gravitation, escape speed and circular orbits.

(a) (i) The term *escape speed* is often defined as the minimum initial speed an object must have at the surface of a planet in order to escape the gravitational attraction of the planet. Explain what is meant by the phrase *"to escape the gravitational attraction of the planet"*. *[2]*

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(ii) The gravitational potential V, at the surface of a spherical body of radius r and mass M is given by

$$V = -G\frac{M}{r}.$$

Show that the escape speed for a projectile, from the surface of the body, is given by

$$v_{escape} = \sqrt{\frac{2GM}{r}}.$$ *[3]*

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(b) The asteroid Toro has a radius of about 5 km and a mass of about 2×10^{15} kg. Estimate the minimum speed with which an astronaut would have to jump off the surface of Toro if he were to escape the gravitational attraction of Toro. *[2]*

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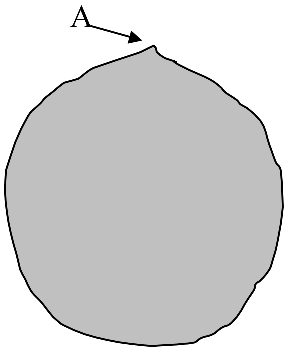
(Question A2 continued)

(c) (i) The diagram below represents the asteroid Toro.



An astronaut runs up to the top of a hill, at A, and jumps off horizontally. Determine the speed with which he would have to launch himself in order to go into a low, circular orbit. *[3]*

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(ii) Sketch on the diagram above the path an astronaut might follow if he launched himself at about $\frac{3}{4}$ of the speed required for a circular orbit. *[1]*

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OPTION B — ATOMIC AND NUCLEAR PHYSICS EXTENSION

B1. This question is about the hydrogen emission spectrum.

Diagram 1 shows some of the energy levels for the hydrogen atom and Diagram 2 shows a line emission spectrum for the hydrogen atom. (The diagrams are not to scale.)

Visible light is emitted when electrons in higher energy states make transitions down to the $n = 2$ state. In Diagram 1 a transition is indicated between the $n = 5$ and $n = 2$ states. In Diagram 2, wavelengths, in nanometres, are indicated at the limits of three series of emission lines, *e.g.* the Paschen series lies between the wavelengths 820 nm and 1875 nm.

Diagram 1

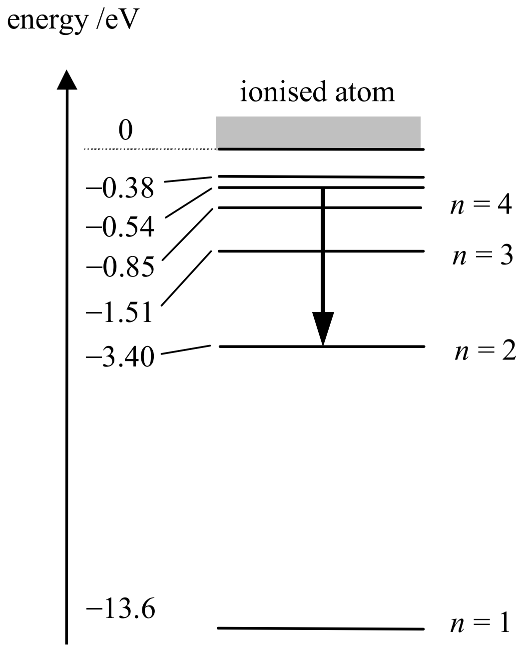
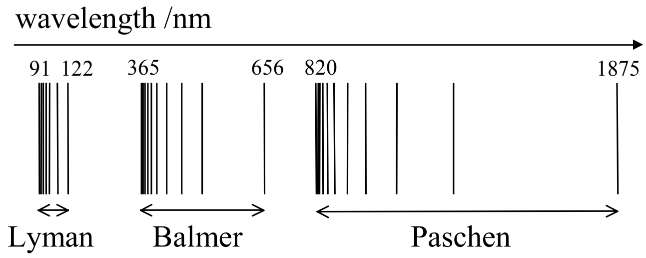


Diagram 2



(a) Diagram 2 shows that the emission lines occur in three series, with the lines crowded at one end of each series and spread out at the other. Referring to the energy levels of Diagram 1, explain how the series arise and why the lines become crowded towards the short wavelength limit. *[4]*

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(Question B1 continued)

(b) On Diagram 2 mark the spectral line that corresponds to the transition indicated in Diagram 1. *[2]*

(c) Calculate the wavelength of the photon emitted in the transition indicated in Diagram 1. *[2]*

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B2. This question is about the dual nature of radiation and matter.

(a) Give **one** example of a phenomenon that supports the particle-like behaviour of light. *[1]*

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(b) Give **one** example of a phenomenon that supports the wave-like behaviour of matter. *[1]*

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(c) Explain why large *particles* such as tennis balls do not exhibit a detectable wave nature. *[3]*

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B3. This question is about nuclear fusion processes.

(a) One of the reactions occurring in stars produces deuterons by the fusion of two hydrogen nuclei. The equation for this reaction is

$$ {}^{1}_{1}\mathrm{H} + {}^{1}_{1}\mathrm{H} \rightarrow {}^{2}_{1}\mathrm{H} + \mathrm{e}^{+} + \nu . $$

This reaction only occurs at very high temperatures.

(i) What do the symbols e^{+} and v represent? *[2]*

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(ii) What subsequently happens to the particle represented by e^{+}? *[1]*

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(iii) Explain why the reaction only occurs at very high temperatures. *[2]*

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(b) The deuterons undergo further fusion reactions to produce helium-3 nuclei ${}^{3}_{2}\mathrm{He}$, which then fuse to produce helium-4. The equation for the latter reaction is

$$ {}^{3}_{2}\mathrm{He} + {}^{3}_{2}\mathrm{He} \rightarrow {}^{4}_{2}\mathrm{He} + {}^{1}_{1}\mathrm{H} + {}^{1}_{1}\mathrm{H}. $$

Explain why this reaction requires a greater temperature than that required for the fusion of hydrogen nuclei. *[2]*

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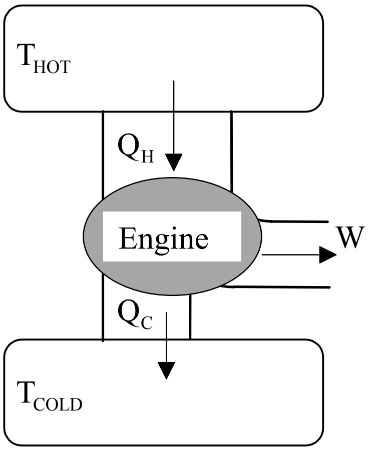
OPTION C — ENERGY EXTENSION

C1. This question is about efficiency and degraded energy in the context of an automobile engine.

The diagram below shows the energy flow scheme for a heat engine.



(a) The maximum temperature attainable when fossil fuel is burnt in a heat engine is about 2400 K. Estimate the maximum theoretical efficiency for such a heat engine when it is operated under normal conditions, exhausting to the atmosphere. *[3]*

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(b) Automobile engines are fossil-fuel powered heat engines and in reality they have efficiencies much less than the maximum theoretical efficiency estimated above. Give **two** reasons why this may be. *[2]*

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(Question C1 continued)

(c) A certain automobile engine has an efficiency of about 20 %. If the engine produces 35 kW of mechanical power during operation, calculate how much thermal energy is lost to the atmosphere per second. *[3]*

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(d) The energy lost to the atmosphere in part (c) above is said to be *degraded*. Explain what *degraded* means in this context. *[2]*

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(e) The second law of thermodynamics can be stated as *"All irreversible processes increase the entropy of the universe."* Explain how the second law, stated in this form, relates to *energy degradation*. *[2]*

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C2. Briefly describe **two** advantages and **two** disadvantages of the use of solar radiation as a renewable energy source.

Advantages: . . . . *[2]*

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Disadvantages: . . . . *[2]*

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C3. This question is about efficiencies of energy conversion processes. The table below gives the average percentage efficiencies for a number of energy conversion devices or processes.

Conversion FROM ↓	**Conversion TO**			
	mechanical	**electrical**	**chemical**	**thermal**
mechanical	—	99 % (electric generator)		100 % (heating by friction)
electrical	93 % (electric motor)	99 % (transformer)	72 % (storage battery)	100 % (electrical heating element)
gravitational potential	86 % (water turbine)	85 % (hydroelectric power plant)	—	—
chemical	—	96 % (storage battery)	—	—

The table shows that mechanical energy may be converted to thermal energy (through friction) and electrical energy may be converted to thermal energy (via an electrical heating element) with an efficiency of 100 %.

(a) Explain why these processes do not violate the second law of thermodynamics. *[2]*

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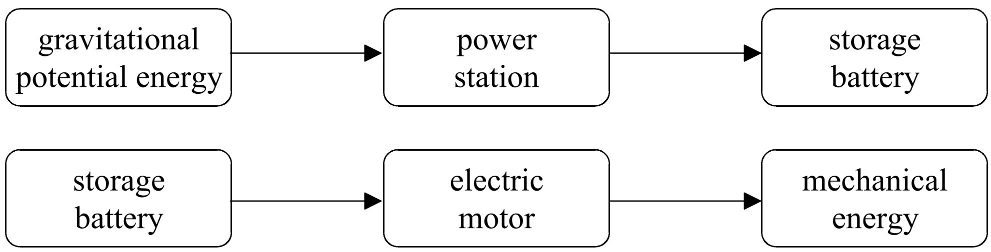
(b) The mechanical energy to drive an electric vehicle is obtained from storage batteries that need to be recharged. The energy-flow diagram below shows the processes involved if the batteries are recharged by electricity produced in a hydroelectric power station.



Use the table above to calculate the overall efficiency for producing mechanical energy from gravitational potential energy in this way. *[2]*

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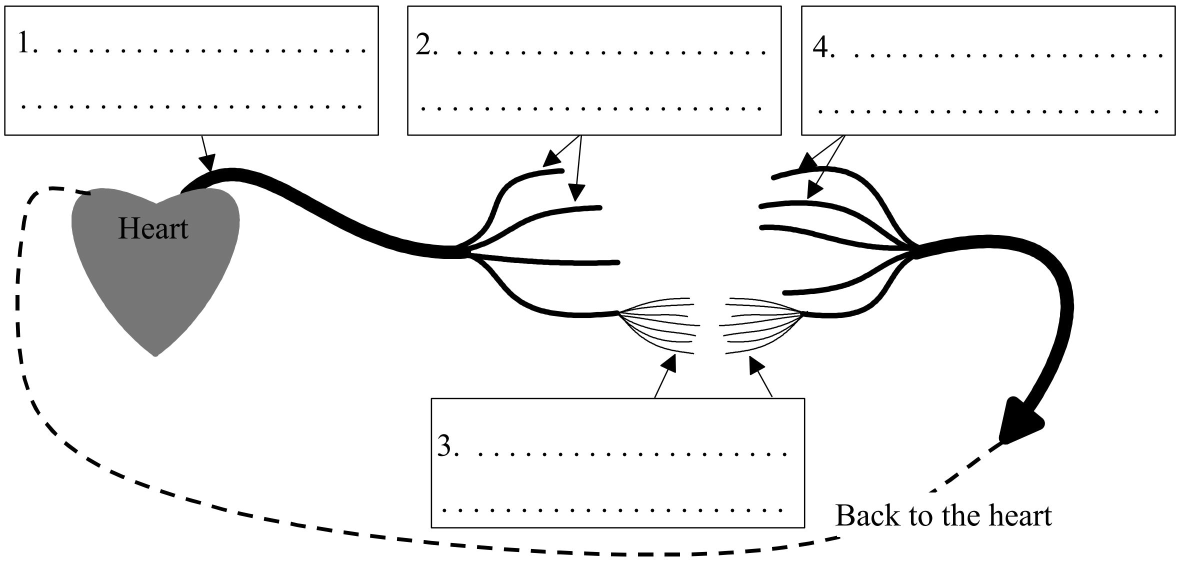
OPTION D — BIOMEDICAL PHYSICS

D1. This question is about blood flow in the human cardiovascular system.

The human cardiovascular system is very complex but a simplified diagram is shown below.

(a) Name the parts of this system by filling in the labels on the diagram. *[2]*



(b) As the blood moves away from the heart, the blood vessels divide and rapidly increase in number in such a way that the total cross-sectional area of the vessels increases. Explain how this increasing total cross-sectional area affects the mean blood velocity as the blood moves from the heart through the arterial system. *[2]*

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(c) The simplified diagram of the human cardiovascular system shown above is considered "closed", *i.e.* no blood escapes or enters the system. Use the data below to calculate the average speed of blood flow in the major arteries of the body.

heart output (volume per unit time)	$100\ cm^3\ s^{-1}$
total cross-sectional area of all major arteries	$8\ cm^2$

[2]

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D2. In this question you will need to use scaling arguments.

After a swim you emerge, dripping wet, carrying a thin layer of water over your body. The mass of water you carry is approximately proportional to your surface area.

(a) Show that the ratio: $\dfrac{\text{extra mass due to water}}{\text{normal body mass}}$, is proportional to $\dfrac{1}{L}$, L being a linear measure of the size of the person. *[2]*

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(b) The mass of water carried by a person emerging after a swim is about 1 % of normal body mass. Estimate the mass of water, as a percentage of normal body mass, carried out by a fly that has been totally immersed. *[3]*

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D3. This question is about the detection of sound by the human ear.

(a) State the approximate range of frequencies that are audible to the young, healthy human ear. *[1]*

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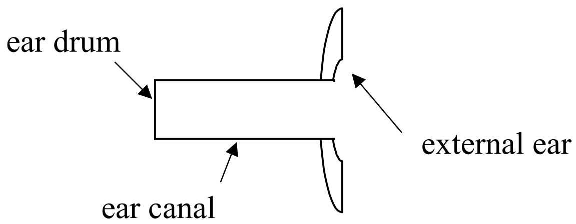
(b) The ear canal can be approximately modelled as a tube about 2.7 cm long, open at one end and closed at the other end by the eardrum, as shown in the diagram below.



Resonance in this tube enhances the ear's sensitivity at frequencies close to the resonant frequencies.

(i) Sketch on the diagram above a representation of the standing wave corresponding to the fundamental mode for the ear canal resonance. *[1]*

(ii) Calculate the fundamental resonant frequency. The speed of sound in air is $343\ \text{m s}^{-1}$. *[3]*

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(c) Describe the role that the cochlea plays in human hearing. *[4]*

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OPTION E — HISTORICAL PHYSICS

E1. This question is about the development of heliocentric models of the solar system.

(a) (i) Draw a sketch to show some typical planetary paths in an **early** *heliocentric model* of the solar system. *[1]*

(ii) Explain how the Copernican model of the solar system accounted for the observed motions of the Sun and the stars. *[2]*

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(b) (i) State an observation made by Galileo that supports a heliocentric model of the solar system. *[1]*

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(ii) Explain in what way a geocentric model, such as Ptolemy's, fails to account for this observation. *[2]*

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(Question E1 continued)

(c) Describe, with the aid of a diagram, how the heliocentric model of Kepler differed from that of Copernicus. *[2]*

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(d) Kepler's laws for the motions of the planets were *empirical* relationships.

(i) What is meant by the term *empirical relationship*? *[1]*

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(ii) What **fundamental** laws later accounted for Kepler's empirical laws of planetary motion? *[2]*

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E2. Below, in italics, is a typical quotation found in textbooks, on the *Energy Concept*.

"Although a number of scientists had hypothesized that heat was ***motion*** *rather than* ***substance****, much of the credit for firmly establishing this view goes to Benjamin Thompson [Count Rumford]."*

(a) Explain the meaning of *heat* as a *substance*. *[1]*

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(b) Explain the meaning of *heat* as *motion*. *[1]*

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(c) What observations allowed Benjamin Thompson to reach this conclusion? *[2]*

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Joule's experiments quantitatively established *heat* as a form of energy. One of the earliest experiments he attempted (during his honeymoon, so the story goes …) was to determine whether the water at the bottom of a waterfall was measurably hotter than that at the top.

(d) Estimate the temperature rise for water per metre of height through which the water falls. Take the specific heat capacity of water to be $4\,200\,\mathrm{J\,kg^{-1}\,K^{-1}}$. *[2]*

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E3. Studies of the photoelectric effect produced a number of experimental observations that could not be explained by the wave model of light. One of these is that there exists a cut-off frequency below which no electron emission occurs no matter how intense the incident light.

Provide an explanation of this observation in terms of the photon model for light. *[3]*

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OPTION F — ASTROPHYSICS

F1. This question is about deducing properties of stars from observational and calculated data.

(a) The table below gives data concerning the stars Deneb and Antares A.

Name	Parallax angle (arcsec)	Apparent magnitude	Temperature (K)	Absolute magnitude
Deneb	—	1.26	10500	-7.1
Antares A	0.006	0.92	3000	-5.1

Calculations are **not** required in answering the following three questions.

(i) What would be the observed colour of the **two** stars? Explain. *[3]*

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(ii) Which star is the brightest as viewed from Earth? Explain. *[2]*

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(iii) Which star is furthest from Earth? Explain. *[2]*

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(Question F1 continued)

(b) Calculate the distance, in metres, from Earth to Antares A. *[2]*

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(c) Antares A is part of a binary system. The companion star Antares B, has a surface temperature of about 15 000 K and a luminosity that is 1/40 of that of Antares A. Calculate the ratio of the surface area of Antares A to that of Antares B. *[3]*

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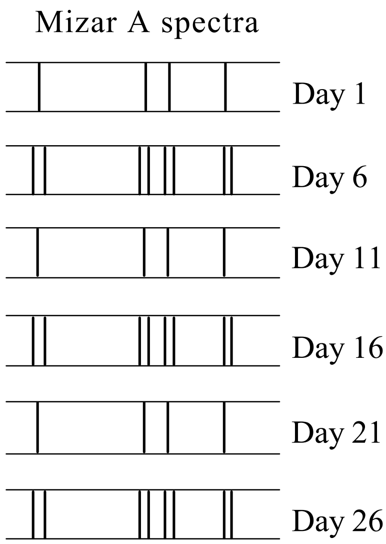
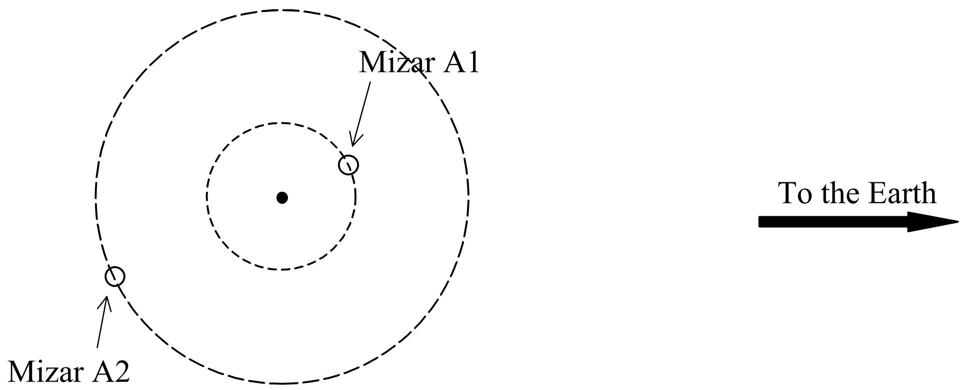
F2. This question is about a spectroscopic binary.

Mizar A is a spectroscopic binary system. Let us call the two stars A1 and A2. The diagram below shows some of the absorption lines in the spectra from the star system measured over a period of time. (Not to scale.)



(a) The two stars orbit around their common centre of mass. The diagram below shows circular orbits.



With the aid of the diagram above explain why the observed absorption lines change as they do with time. *[3]*

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(Question F2 continued)

(b) What is the period of this binary system? *[1]*

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F3. This question is about Olbers' Paradox.

(a) An assumption of most cosmological models is the *cosmological principle*. This states the belief that the universe is homogeneous and isotropic. That is, if we look at a large enough part of the universe, in any direction, we will see the same number and density of stars. Explain how, in the nineteenth century, this principle led Heinrich Olbers to the paradoxical conclusion that the night sky should be bright. *[2]*

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(b) How is Olbers' paradox resolved in the *Big Bang* model of the universe? *[2]*

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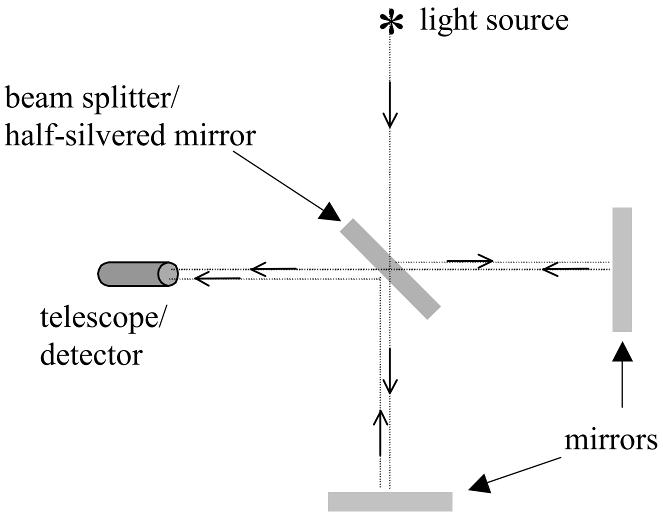
OPTION G — SPECIAL AND GENERAL RELATIVITY

G1. This question is about the Michelson-Morley experiment.

In the Michelson-Morley experiment an interferometer is used in which a beam of light is split into two beams. These travel along different paths and are then recombined and interfere and so form interference fringes. The diagram below shows the main features of such an interferometer.



(a) What was the purpose of the experiment? *[1]*

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(b) What did the results of the experiment indicate? *[1]*

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(c) The experiment was repeated with the whole apparatus rotated through 90° and also repeated at different times of the year. Explain why both of these were done. *[2]*

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(Question G1 continued)

(d) How do the postulates of the special theory of relativity account for the results obtained in the Michelson-Morley experiment? *[2]*

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G2. Suppose that some time in the future it will be possible for astronauts to travel to Alpha Centauri, 4.2 light years away, at a constant speed of $0.95c$.

(a) How many years would it take for them to get there as measured by

(i) observers in the Earth's frame of reference? *[1]*

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(ii) the astronauts? *[3]*

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(b) On arrival at Alpha Centauri, having forgotten their shopping list, they immediately set out on the return journey, at the same speed. On their arrival back on Earth how much time has passed, since the astronauts first left Earth, as measured by

(i) observers on the Earth? *[1]*

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(ii) the astronauts? *[1]*

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(This question continues on the following page)

(Question G2 continued)

(c) In the situation in part G2(b), the astronauts find that after the return journey a different amount of time has passed according to their clocks compared to the clocks of their friends who remained on Earth.

(i) This is often referred to as a *paradox*. Explain why the term *paradox* is used. *[2]*

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(ii) Explain how this apparent *paradox* is resolved. *[2]*

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G3. General relativity describes the change that takes place in an electromagnetic signal emitted radially outwards from the surface of a massive body.

(a) What is this change? *[2]*

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(b) Describe briefly **one** experiment in which this effect has been measured. *[2]*

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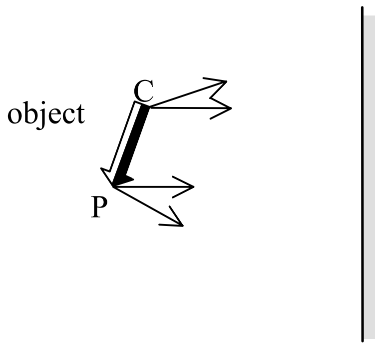
OPTION H — OPTICS

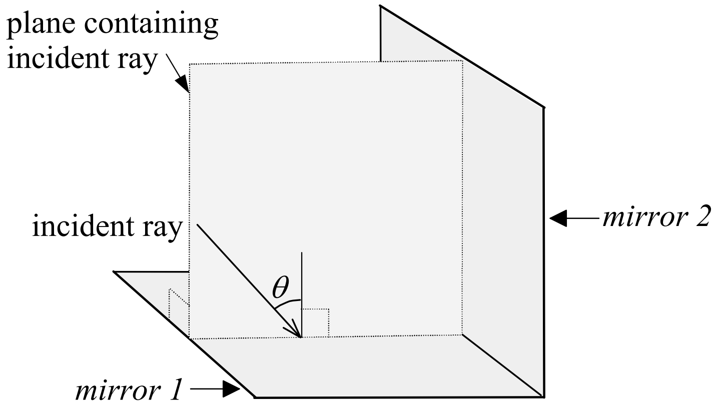
H1. This question is about reflection from plane mirrors.

(a) The diagram below shows four light rays leaving points C and P of the object. The light rays are directed towards a plane mirror. On the diagram, extend the rays to locate the image formed by the mirror of the corner C and the point P. Then draw in the image. *[3]*



(b) A *corner reflector* consists of two plane mirrors fastened together at right angles, as shown in the diagram below. The arrangement has the property that a ray of light, incident in a plane perpendicular to the mirrors, is returned with its direction exactly reversed after reflection from both mirrors.

The diagram shows an incoming ray, incident at an angle θ to *mirror 1*.



(i) Complete the path of the ray and prove, using geometric arguments, that it is reflected from *mirror 2* with its direction reversed relative to the incoming direction. *[3]*

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(Question H1 (b) continued)

(ii) Such an arrangement also works in 3-dimensions where a *corner reflector* consists of three plane mirrors fastened together to form the corner of a cube. State **one** application where such reflectors would be useful. *[1]*

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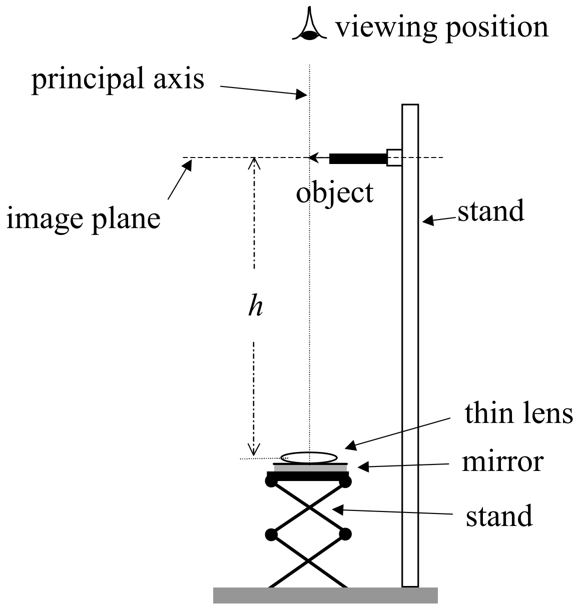
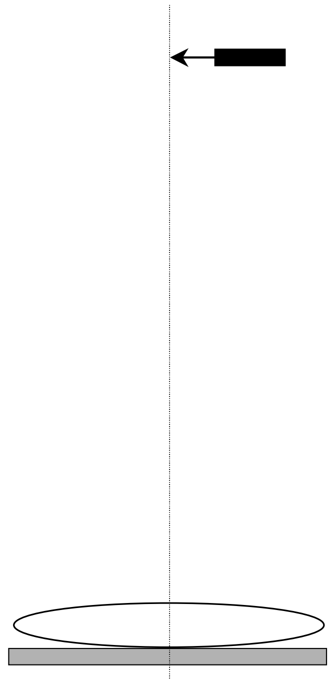
H2. A method for determining the focal length of a thin convex lens is illustrated in the diagram below. The lens is placed on a plane mirror. The combination is placed on a stand of adjustable height. An object with a fine point is held above the combination with the fine point at the principal axis. While viewing from above, the distance h is adjusted until an image is observed to coincide with the position of the object. The distance h then corresponds to the focal length of the lens.



(a) On the diagram below, with the aid of a ray diagram, explain how the image is formed when the system is in proper adjustment. Refraction details at the lens are not required. *[4]*



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(Question H2 continued)

(b) Is the image real or imaginary? *[1]*

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(c) What is the magnification? *[1]*

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(d) If the object was moved up, *i.e.* further from the lens, how would the position of the image change? *[1]*

. . . .

H3. This question is about interference due to two and more slits.

Diagram 1 below shows the central part of the intensity pattern produced in a "Young's double slit" experiment using light of wavelength 434 nm. The arrangement used to produce the pattern is shown in Diagram 2.

Diagram 1

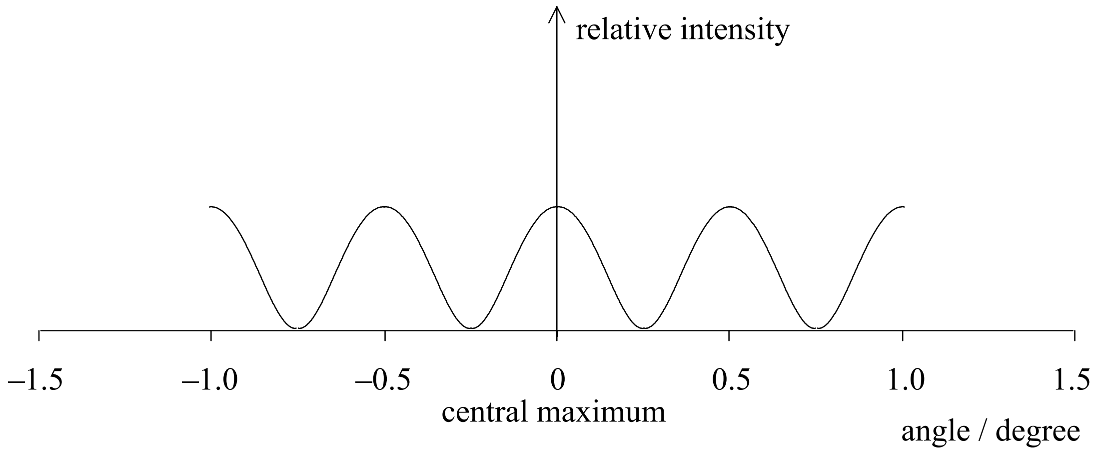
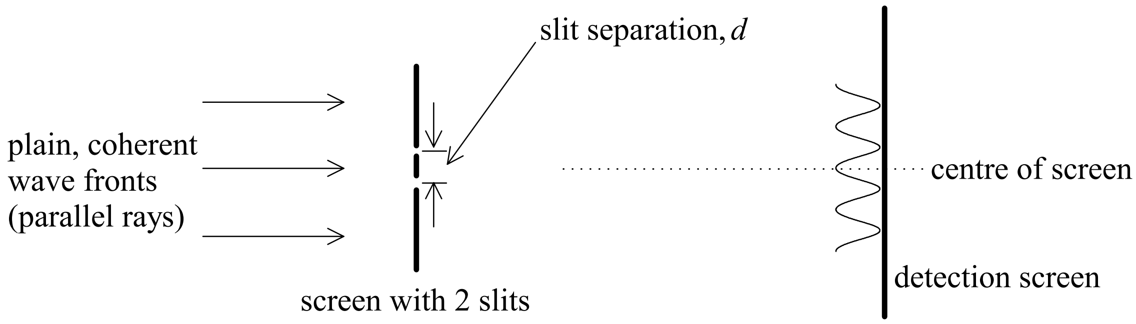


Diagram 2



(a) Determine the slit separation, *d*. *[3]*

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(b) Sketch on Diagram 1, the intensity pattern that would be produced by four slits with the same separation as in (a) above. *[3]*