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

M02/430/H(3)

PHYSICS
HIGHER LEVEL
PAPER 3

Friday 3 May 2002 (morning)

1 hour 15 minutes

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
	/30	/30	/30
	/30	/30	/30
	TOTAL /60	TOTAL /60	TOTAL /60

OPTION D — BIOMEDICAL PHYSICS

D1. This question is about fluid flow in the context of the human cardiovascular system. Poiseuille's equation can be written as

$$\Delta P = \left(\frac{8\eta L}{\pi r^4}\right) Q$$

where ΔP is the pressure drop across a tube of length L and radius r, through which there is a volume flow of fluid at a rate Q.

(a) (i) State what physical quantity the symbol η is a measure of. *[1]*

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(ii) Give the SI units of Q and of η. *[2]*

Q: . . . . . .

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η: . . . . . .

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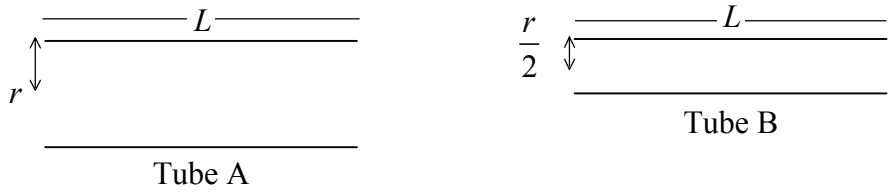
(b) (i) The diagram below shows two tubes A and B, of the same length L, through which the **rate of fluid flow is the same**. The radius of tube B is half that of tube A.



How does the pressure drop ΔP_B, across tube B, compare to ΔP_A, across tube A? *[3]*

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(Question D1 (b) continued)

(ii) If the resistance to fluid flow of tube A is R, what is the resistance of tube B in terms of R? *[1]*

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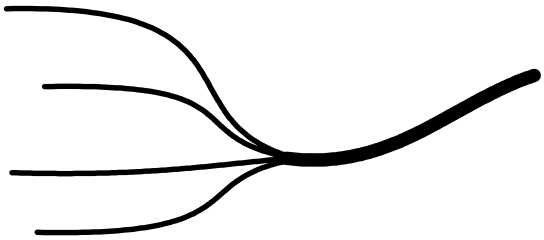
(iii) Four similar tubes come together smoothly to form a single tube as shown below.



If the resistance to fluid flow of each of the four tubes is R, what is the resistance of the single tube in terms of R? *[2]*

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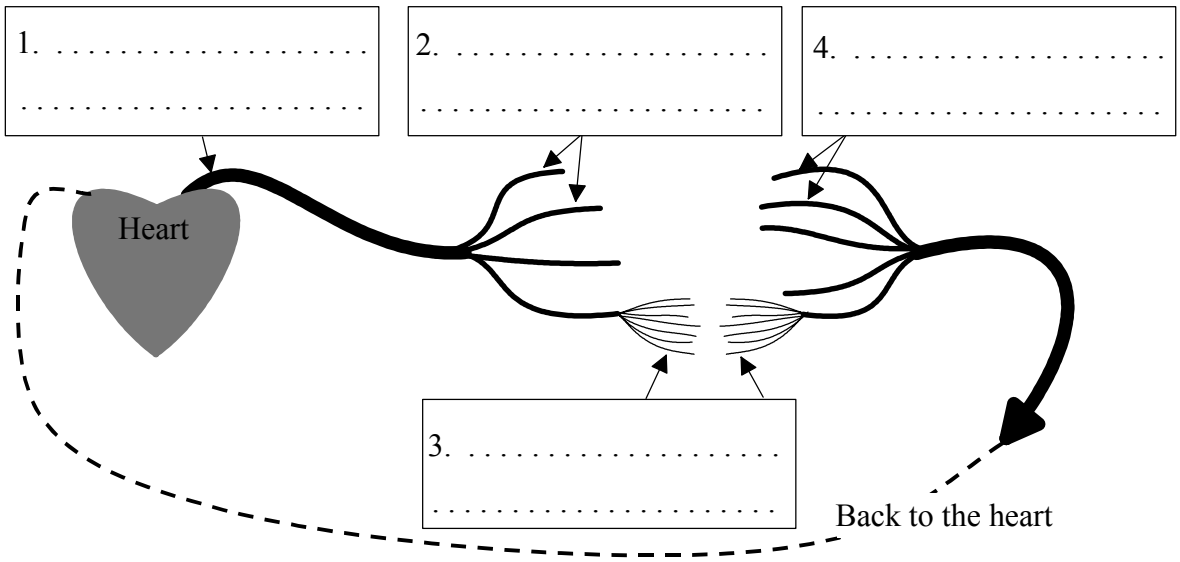
(Question D1 continued)

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

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



(ii) 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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(iii) 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: $\frac{\text{extra mass due to water}}{\text{normal body mass}}$, is proportional to $\frac{1}{L}$, 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 ultrasound and imaging.

(a) What is meant by the term *ultrasound*? *[1]*

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(b) Describe how images are produced using ultrasound. *[3]*

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(c) Explain why high frequency ultrasound is better for producing diagnostic images than low frequency ultrasound. *[2]*

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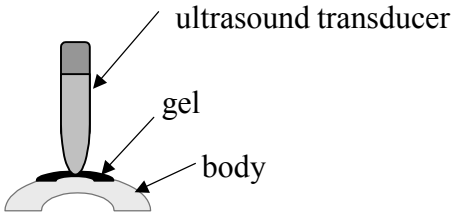
(d) The diagram below shows an ultrasonic generator / detector placed in contact with the skin. A jelly-like substance, gel, is used between the transducer and the skin. Why is this? *[2]*



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(Question D3 continued)

(e) Give **two** examples of circumstances under which it is preferable to use ultrasound rather than X-rays for imaging. *[2]*

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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. This question is about steam engines and energy degradation.

Below, in italics, are two typical quotations, found in textbooks, on the steam engine and energy degradation. These are followed by a number of questions that are related to the quotation. Answer all the questions.

(a) *"For the next half of the century, engineers like James Watt devised ways to make the Newcomen steam engine more efficient."*

(i) To which century does the quote refer? *[1]*

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(ii) Diagram 1 below is a schematic diagram of a later-model steam engine. What feature of this engine was **not** a part of the Newcomen engine? *[1]*

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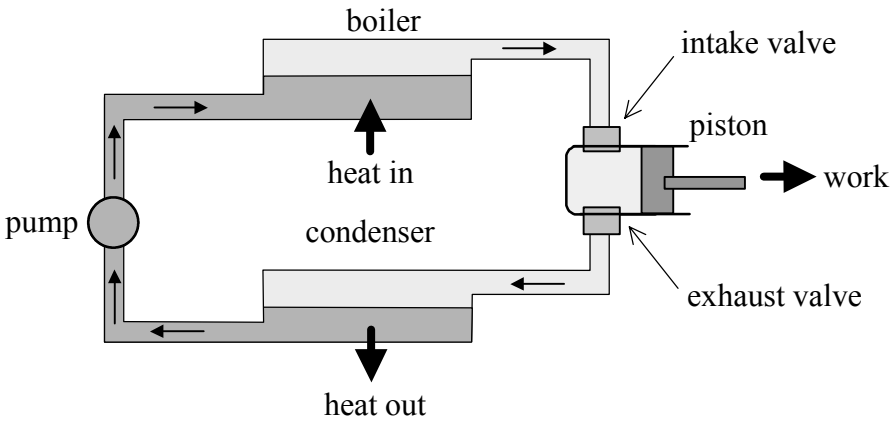
Diagram 1



(iii) With reference to Diagram 1, what are the factors that determine the efficiency of an **ideal** steam engine? *[2]*

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(Question E2 continued)

(b) *"When an engine operates, ... it transforms energy, and it does that at the cost of degrading a certain amount of high-quality, high-temperature energy into low-quality, low-temperature energy."*

(i) With reference to Diagram 1 opposite, identify the source of "*high-quality*" and the reservoir of *"low-quality"* energy. *[1]*

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(ii) Explain what *degraded energy* means in the context of a steam engine. *[2]*

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(c) 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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E3. This question is about the photoelectric effect.

In studying the photoelectric effect, two experimental observations that could not be explained by the wave model of light are

- that there exists of a cut-off frequency below which no electron emission occurs no matter how intense the incident light.
- that there is no measurable time delay for electron emission no matter how weak the incident light intensity.

Provide an explanation of these **two** observations in terms of the photon model for light. *[4]*

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E4. This question is about the conservation laws that govern the production, decay and interactions of fundamental particles.

Use the data in the table below to answer the following questions.

Particle		Mass $\left(\mathbf{MeV/c^2}\right)$	Charge (C)	Baryon number	Lepton number
Neutron	(n)	939.6	0	+1	0
Proton	(p^+)	938.3	+1	+1	0
Antiproton	(p^-)	938.3	–1	–1	0
Electron	(e^-)	0.511	–1	0	+1
Antielectron	(e^+)	0.511	+1	0	–1
Pion	(π^+)	139.6	+1	0	0
Pion	(π^-)	139.6	–1	0	0
Lambda	(Λ^0)	1116	0	+1	0
Neutrino	(ν)	0	0	0	+1
Antineutrino	($\overline{\nu}$)	0	0	0	–1
Gamma photon	(γ)	0	0	0	0

(This question continues on the following page)

(Question E4 continued)

The decay processes given below **do not** occur in nature. Determine **and** list the conservation laws that are violated in these processes. For each suggest a possible correct decay / interaction process.

Assume that the decaying / interacting particles are initially at rest.

(i) Neutron decay: $n \rightarrow p^+ + \pi^-$.

Does not occur because: *[2]*

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Process which does occur is: $n \rightarrow$

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(ii) Lambda decay: $\Lambda^0 \rightarrow p^- + \pi^+$.

Does not occur because: *[2]*

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Process which does occur is: $\Lambda^0 \rightarrow$

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(iii) Electron annihilates with a positron: $e^- + e^+ \rightarrow \gamma$.

Does not occur because: *[2]*

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Process which does occur is: $e^- + e^+ \rightarrow$.

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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 radius of Antares A to that of Antares B. *[4]*

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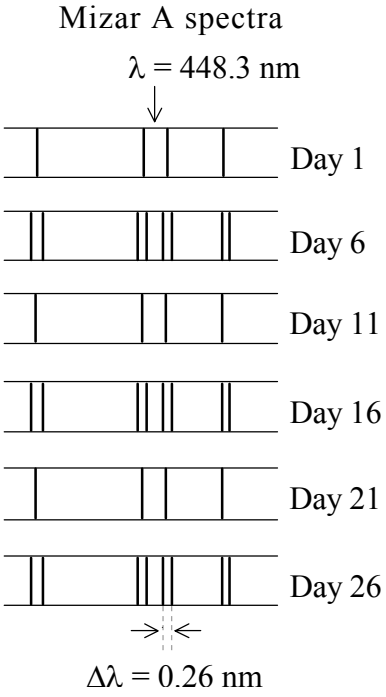
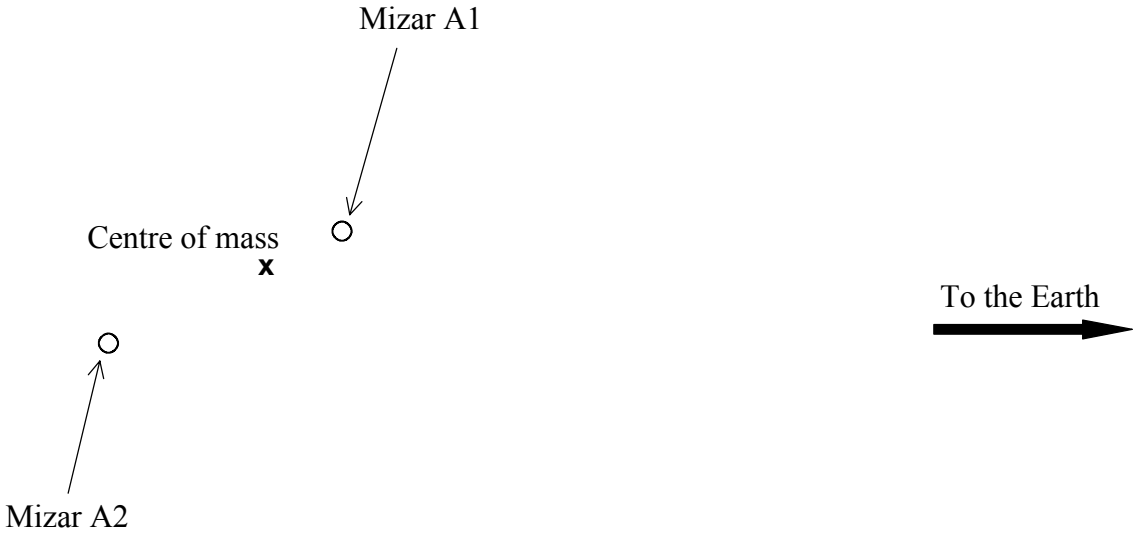
F2. This question is about a spectroscopic binary.

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) With the aid of the diagram below, describe the motion of the system and explain why the observed absorption lines change as they do with time. *[4]*



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(Question F2 continued)

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

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(c) Using the wavelength values given in the diagram, calculate the observed speed of Mizar A1 relative to Mizar A2. *[3]*

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(d) What property of the binary star system can be deduced from the period and velocity measurements above? *[1]*

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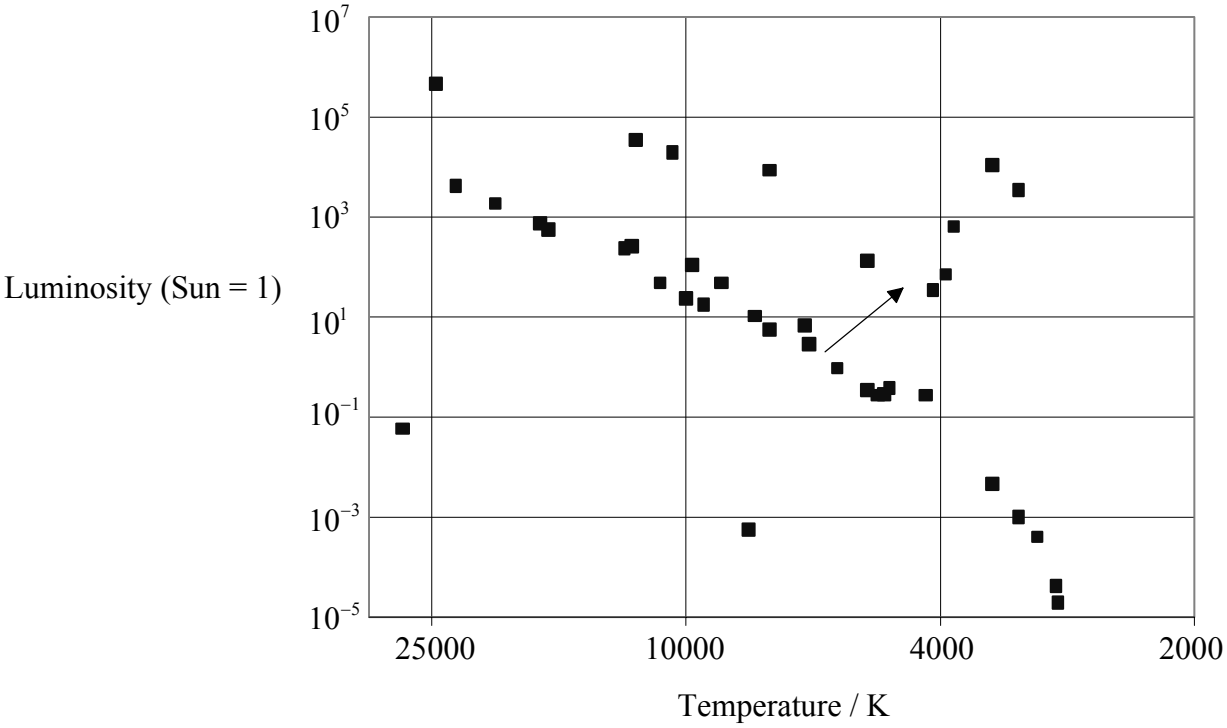
F3. This question is about the Hertzsprung-Russell diagram and stellar evolution. The diagram below shows a plot of luminosity versus temperature for a number of stars.



(a) Indicate on the diagram the main sequence stars and the regions that contain white dwarfs and red giants. *[2]*

(b) The arrow on the diagram represents a change in the state of a star.

(i) How do the temperature, luminosity and size of this star change in this process? *[3]*

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(ii) Briefly describe the physical processes that lead to the changes in temperature, luminosity and size described in (i) above. *[3]*

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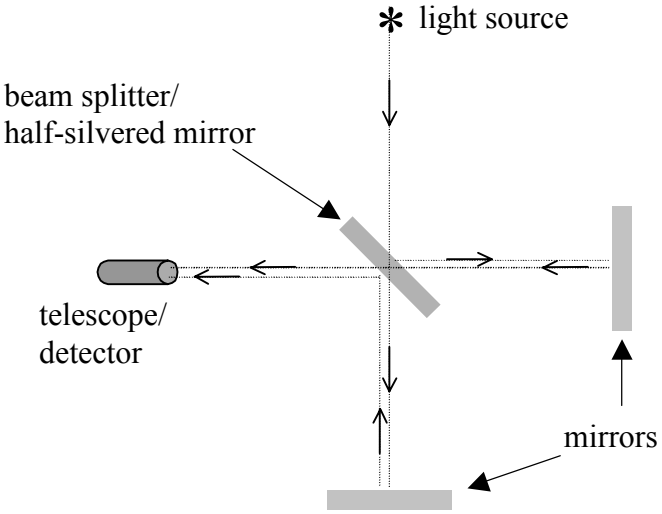
OPTION G — SPECIAL AND GENERAL RELATIVITY

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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(This question continues on the following page)

(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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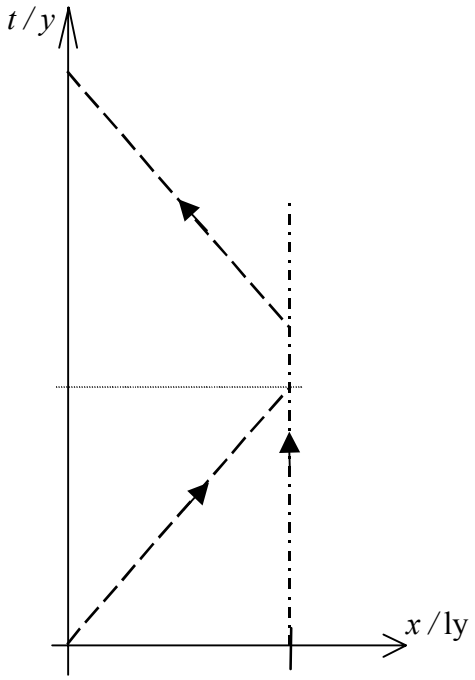
G2. Suppose that some time in the future it will be possible for astronauts to travel from Earth to Alpha Centauri, 4.2 light years away.

The space-time diagram below shows such a return journey from the point of view of observers in the Earth's frame of reference. The journey is made at a constant speed of 0.95*c*, and the astronauts spend 1.0 y at Alpha Centauri. The origin of time is when the astronauts leave the Earth.



(a) Annotate the time axis with the time of arrival, in years, at Alpha Centauri and the time of return to Earth. *[2]*

(b) On their arrival at Alpha Centauri the astronauts send a radio message back to Earth. Indicate on the space-time diagram the path of the message and it's time of arrival at Earth. *[2]*

(This question continues on the following page)

(Question G2 continued)

(c) How long does the journey take, from leaving Earth and returning back to Earth, as measured by the astronauts? *[3]*

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(d) In the above situation, 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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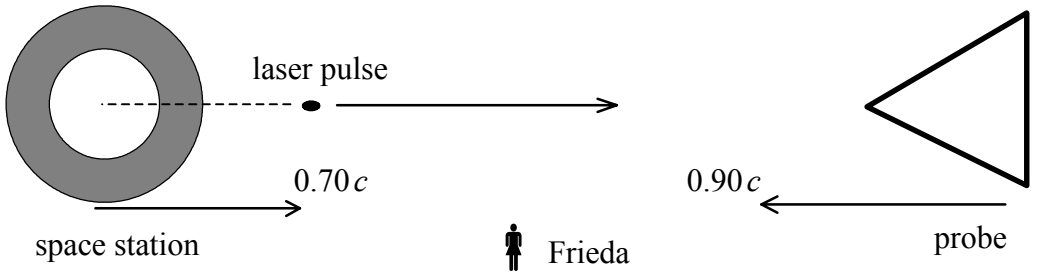
G3. This question is about relative velocities.

An inertial observer, Frieda, determines that a space probe and a space station are travelling along the same straight line but in opposite directions. She measures the speed of the space station to be speed 0.70*c* and that of the probe to be 0.90*c*. At some time before they collide the space station signals the probe by sending a laser-light pulse in a straight line towards the probe.



(a) What value does classical (Galilean) velocity addition give for the speed of the laser pulse relative to

(i) Frieda? *[1]*

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(ii) the probe? *[1]*

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(b) What would be the speed of the laser pulse as measured by

(i) Frieda? *[1]*

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(ii) instruments onboard the probe? *[1]*

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(c) What would be the speed of the space probe as measured by observers on the space station? *[3]*

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G4. Modern communications systems rely heavily on networks of geostationary satellites orbiting at a distance of about 36×10^6 m above the Earth's surface. Receivers on Earth detect signals relayed by these satellites.

(a) A satellite emits a frequency of 117.8 MHz. According to general relativity, explain whether the frequency detected by a receiver on Earth would be greater or less than 117.8 MHz. *[2]*

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(b) Use the relationship $\frac{\Delta f}{f} = g\frac{\Delta h}{c^2}$ to estimate the shift in frequency Δf, that would be detected by a receiver on Earth as a result of the Earth's gravitational field, g. *[2]*

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(c) The relationship used in (b) above is only accurate when g can be taken as a constant *i.e.* when Δh << the radius of the Earth, 6.4×10^6 m. In view of this, explain whether your calculation in (b) is likely to be an overestimate **or** an underestimate. *[2]*

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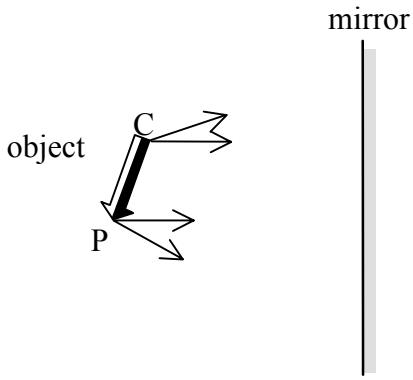
OPTION H — OPTICS

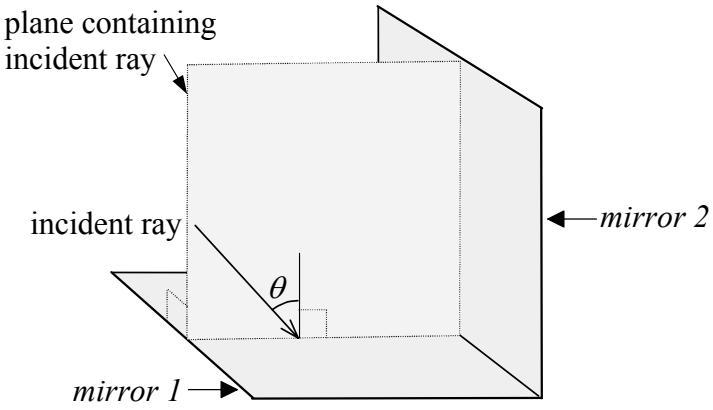
H1. This question is about reflection from plane mirrors.

(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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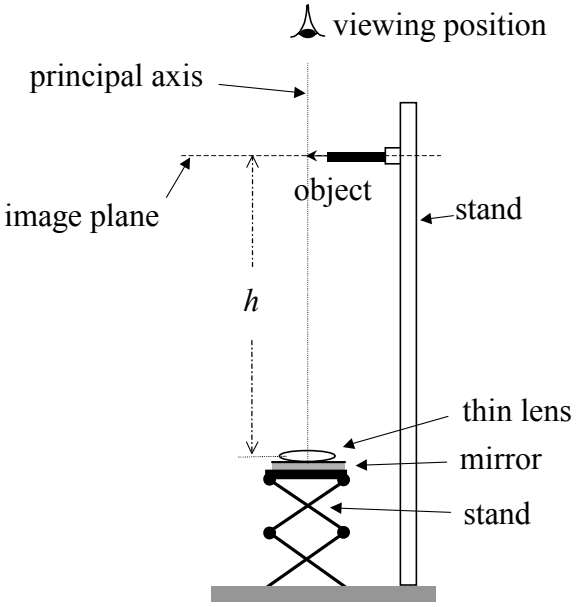
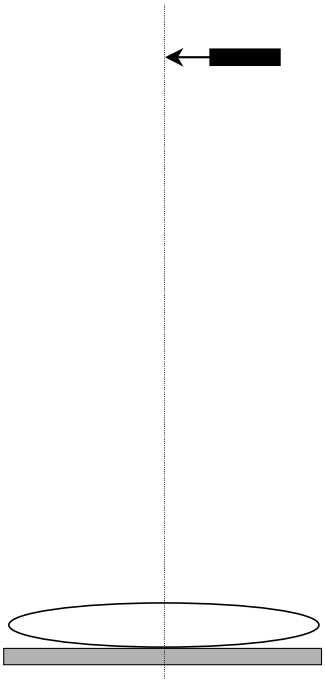
H2. A method for determining the focal length of a thin convex lens is illustrated in the diagram below. The lens is placed on a plane mirror. The combination is placed on a stand of adjustable height. An object with a fine point is held above the combination with the fine point at the principal axis. 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]*

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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

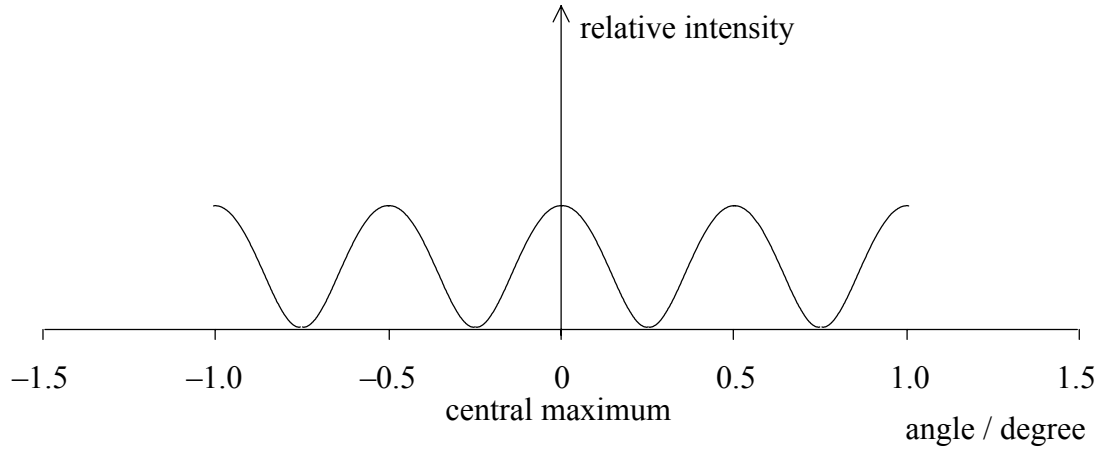
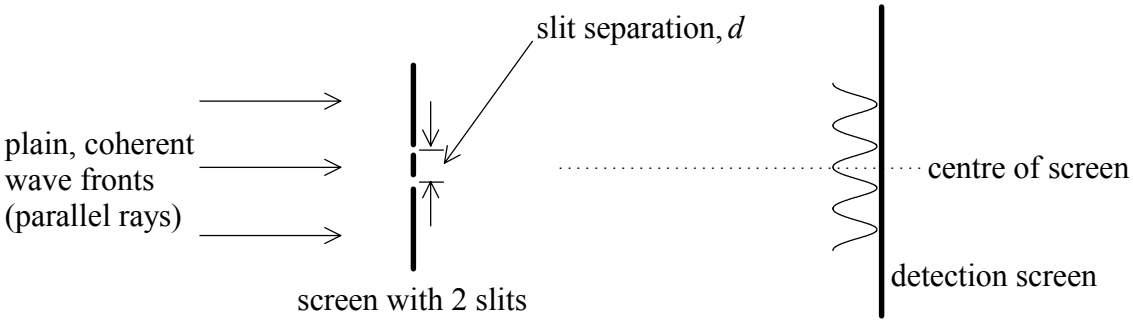


Diagram 2



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

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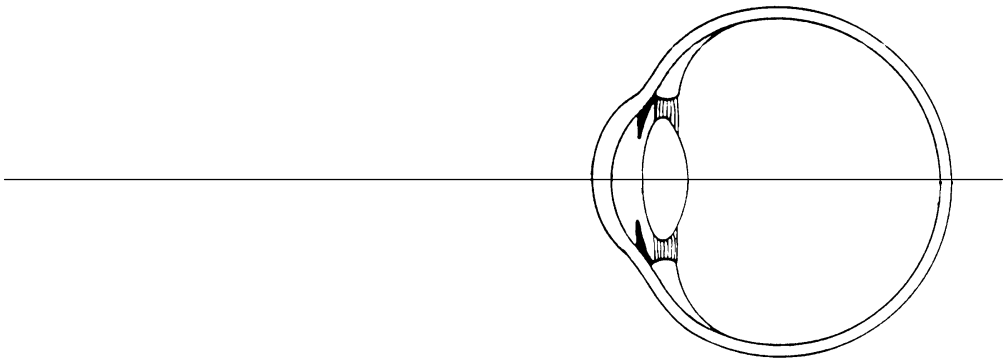
(b) Sketch on Diagram 1, the intensity pattern that would be produced by four slits with the same separation as in (a) above. *[3]*

H4. This question is about myopia and the resolution of the human eye.

Myopia (nearsightedness) is a common eye condition in which the person is not able to focus light from distant sources onto the retina.

(a) The diagram below represents a cross section of the human eye. On the diagram, draw in two light rays from a distant light source and show where they would be brought to a focus for a myopic person. Details of refraction at the cornea and lens are **not** required. *[2]*



(b) What type of spectacle lens is used to correct this problem? *[1]*

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(c) A particular nearsighted person is unable to see objects clearly when they are beyond 0.70 m (the *far point*). Of what focal length should the prescribed spectacle lenses be, in order to correct this problem.

(Note that the function of the spectacles is to produce an image of a distant object at the person's far point.) *[2]*

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(This question continues on the following page)

(Question H4 continued)

(d) You will need the following data to answer this question.

Pupil diameter	4.0 mm
Refractive index of the vitreous humour	1.337

(i) The wavelength of light at which the eye is most sensitive is 550 nm. Calculate what the wavelength becomes once the light enters the vitreous humour.

(Note that the refractive index of a material is given by $n = \frac{c}{c_{medium}}$, where c is the speed of light (in vacuum) and c_{medium} is the speed of light in the medium.) *[2]*

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(ii) What must be the minimum angular separation between two point objects if they are to be just resolved by the average human eye? Assume the resolution of the eye is limited only by diffraction at the pupil. *[3]*

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