N04/4/PHYSI/HP3/ENG/TZ0/XX+

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PHYSICS
HIGHER LEVEL
PAPER 3

School code

Monday 8 November 2004 (morning)

1 hour 15 minutes

Candidate code

INSTRUCTIONS TO CANDIDATES

- Write your school code and candidate code 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 candidate box on your cover sheet.

Option D — Biomedical Physics

D1. This question is about scaling and compares the different methods by which an amoeba and a goldfish absorb oxygen.

An amoeba and a goldfish both live in water and need oxygen to survive. An amoeba is a very small animal composed of a single cell, whereas a goldfish is made up of many cells.

The following information is available.

The rate at which an animal uses oxygen is proportional to its mass.
The rate of oxygen absorption by an amoeba is proportional to its surface area.
A typical amoeba is 8.0×10^{-5} m in length.
A typical goldfish is 5.0 cm in length.
An amoeba cannot live if its rate of oxygen absorption per unit mass falls below 10 % of its normal rate.

(a) Explain how the following quantities scale with the linear dimension *L* of an amoeba.

(i) The surface area. *[1]*

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(ii) The rate of oxygen absorption across the cell surface membrane. *[1]*

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(iii) The rate of oxygen absorption per unit mass. *[2]*

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(This question continues on the following page)

(Question D1 continued)

(b) Consider a "giant" amoeba equal in length to a goldfish. Calculate the ratio

$$\frac{\text{the rate of oxygen absorption per unit mass for the "giant" amoeba}}{\text{the rate of oxygen absorption per unit mass for a typical amoeba}}.$$ *[2]*

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(c) With reference to your answer to (b) suggest **one** reason why a goldfish must have a different means of oxygen intake to an amoeba. *[2]*

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D2. When X-rays are used for diagnostic purposes, beam energies of about 30 keV are used. This results in good contrast on the radiogram because the most important attenuation mechanism is not simple scattering.

(a) Outline the most important attenuation mechanism that is taking place at this energy. *[2]*

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(b) Explain the following terms.

(i) *Attenuation coefficient* *[2]*

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(ii) *Half-value thickness* *[2]*

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(This question continues on the following page)

(Question D2 continued)

(c) The attenuation coefficient at 30 keV varies with the atomic number Z as shown below.

$$\text{Attenuation coefficient} \propto Z^3$$

The data given below list average values of the atomic number Z for different biological materials.

biological material	**atomic number *Z***
fat	5.9
muscle	7.4
bone	13.9

(i) Calculate the ratio

$$\frac{\text{attenuation coefficient for bone}}{\text{attenuation coefficient for muscle}}.$$ *[2]*

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(ii) Suggest why X-rays of 30 keV energy are useful for diagnosing a broken bone but a different technique must be used for examining a fat-muscle boundary. *[4]*

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(This question continues on the following page)

(Question D2 continued)

A patient of mass 60 kg receives a dose equivalent of 3 30 μSv during a chest X-ray. The quality factor (relative biological effectiveness) of X-rays is 1.

(d) (i) Calculate the absorbed dose received by the patient. *[1]*

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(ii) Estimate the total energy received by the patient. *[2]*

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(e) Outline **two** precautions that an X-ray machine operator should take to minimize his/her exposure to X-rays. *[2]*

1. . . . .

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2. . . . .

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(f) State **two** possible biological effects for an X-ray machine operator of not taking suitable precautions. *[2]*

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2. . . . .

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X-rays can also be used in radiation therapy. The X-rays used are of a much higher intensity than those used to take chest X-rays.

(g) (i) Suggest a situation in which radiation therapy might be used. *[1]*

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(ii) Outline the basis of X-radiation therapy. *[2]*

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Option E — The History and Development of Physics

E1. This question is about cathode rays and their properties.

The following is taken from the introduction to an article written in 1895 by Jean Perrin. The article describes an experiment on the newly discovered "cathode rays".

"Two hypotheses have been published to explain the properties of the cathode rays. Some think that this phenomenon, like light, results from vibrations of the ether, or even that it is light of short wavelength… Others think that these rays are formed of matter moving with great velocity…"

(a) Outline how cathode rays were discovered. *[2]*

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(b) The result of Perrin's experiment indicated that cathode rays carry a negative charge. State and explain which of the hypotheses above is supported by this result. *[2]*

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(c) Hertz performed experiments that seemed to indicate that the cathode rays were not deflected by an electric field. State and explain which of the hypotheses is supported by this result. *[2]*

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(This question continues on the following page)

(Question E1 continued)

Two years after Hertz's experiments were performed, experiments were undertaken that enabled the charge-to-mass ratio of the particles in the cathode rays to be measured.

(d) (i) State who was responsible for these experiments. *[1]*

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(ii) Outline the experimental procedure that enabled the charge-to-mass ratio of the particles to be measured. *[3]*

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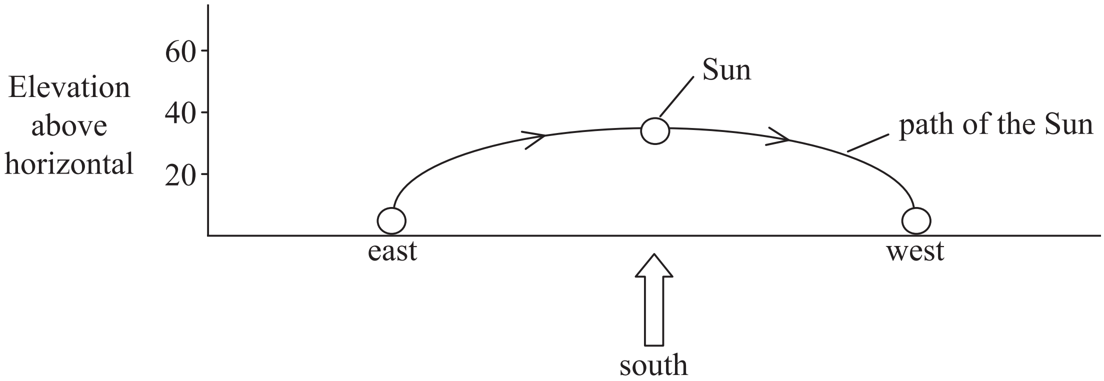
E2. This question is about astronomical observations and their explanation.

The diagram below represents the observed motion of the Sun during a **winter**'s day as seen by an observer **looking south**.



(a) State and explain in which hemisphere the observer is located. *[1]*

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(b) Draw a possible path on the diagram above for the observed motion of the Sun during a summer's day as seen from this location. *[2]*

(c) Explain the path that you have drawn in (b) in terms of

(i) the Aristotelian/Ptolemaic model of the universe. *[2]*

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(ii) the Aristarchian/Copernican model of the universe. *[2]*

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(This question continues on the following page)

(Question E2 continued)

(d) (i) Outline **one** similarity and **one** difference between the observed motion of the stars and that of the planets.

Similarity: . . . . *[1]*

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Difference: . . . . *[1]*

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(ii) State the evidence on which Kepler based his laws of planetary motion. *[1]*

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E3. In a scientific paper published in 1895 Balmer described the discovery of a formula by which the wavelengths of a series of spectral lines of the hydrogen atom (in the visible part of the electromagnetic spectrum) can be represented. Other series for the spectrum of atomic hydrogen were discovered later. The frequencies of the spectral lines in these series all fitted a general empirical formula.

(a) State this general formula and explain any symbols used. *[3]*

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(b) Describe how this formula may be used to determine the wavelengths of the spectral lines in the Balmer series. *[2]*

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(c) Use the formula in (a) to show that the ionisation energy for hydrogen is about 13.6 eV. The Rydberg constant for hydrogen is $1.10\times10^{7}\ \text{m}^{-1}$. *[3]*

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(d) Niels Bohr proposed a model for the hydrogen atom that enabled the empirical formula in (a) to be derived. State **two** limitations of this model. *[2]*

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Option F — Astrophysics

F1. This question is about the properties of the star Arcturus.

The following data is for the star Arcturus.

Distance from Earth / m	Apparent magnitude	Absolute magnitude	Spectral type	Luminosity / W
3.39×10^{17}	– 0.1	– 0.3	K	3.8×10^{28}

(a) Explain the difference between *apparent magnitude* and *absolute magnitude*. *[2]*

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(b) State and explain, with reference to the data, whether Arcturus would be visible without the aid of a telescope on a clear night. *[1]*

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Techniques for determining stellar distances include the use of stellar parallax, spectroscopic parallax and Cepheid variables.

(c) (i) Calculate the distance, in pc, of Arcturus from the Earth. *[1]*

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(ii) State and explain which technique would be most suitable for determining the distance to Arcturus. *[2]*

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(This question continues on the following page)

(Question F1 continued)

(iii) Outline the method you have chosen in your answer to (c) (ii). *[4]*

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(d) State how it may be deduced from the data that the surface temperature of Arcturus is lower than that of the Sun. *[2]*

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(This question continues on the following page)

(Question F1 continued)

The temperature of Arcturus is 4000K.

(e) Calculate

(i) the surface area of Arcturus. *[2]*

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(ii) the radius of Arcturus. *[2]*

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(iii) the wavelength at which the light from Arcturus has its maximum intensity. *[2]*

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(f) Using your answers to (e) deduce the stellar type to which Arcturus belongs. *[2]*

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F2. One of the most intense sources known to radio astronomers is the Galaxy NGC5128. Long exposure photographs show it to be a giant elliptical galaxy crossed by a band of dark dust. It lies about 1.5×10^{7} light years away from Earth.

(a) Describe any differences between this galaxy and the Milky Way. *[2]*

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Hubble's law predicts that NGC5128 is moving away from Earth.

(b) (i) State Hubble's law. *[1]*

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(ii) State and explain what experimental measurements need to be taken in order to determine the Hubble constant. *[3]*

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(c) A possible value for the Hubble constant is $60\,\text{km}\,\text{s}^{-1}\,\text{Mpc}^{-1}$. Use this value to estimate

(i) the recession speed of NGC5128. *[2]*

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(ii) the age of the universe. *[2]*

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Option G — Relativity

G1. This question is about the postulates of relativity.

(a) State the **two** postulates of special relativity. *[2]*

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(b) State and explain which postulate can be predicted from Maxwell's electromagnetic theory of light. *[2]*

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(c) Outline **one** piece of experimental evidence that supports the special theory of relativity. *[3]*

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G2. This question is about relativistic motion.

The radioactive decay of a nucleus of actinium-228 involves the release of a β-particle that has a **total energy** of 2.51 MeV as measured in the laboratory frame of reference. This total energy is significantly larger than the **rest mass energy** of a β-particle.

(a) Explain the difference between *total energy* and *rest mass energy*. *[2]*

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(b) Deduce that the Lorentz factor, as measured in the laboratory reference frame, for the β-particle in this decay is 4.91. *[3]*

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A detector is placed 37 cm from the actinium source, as measured in the laboratory reference frame.

(c) Calculate, for the laboratory reference frame,

(i) the speed of the β-particle. *[2]*

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(ii) the time taken for the β-particle to reach the detector. *[2]*

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(This question continues on the following page)

(Question G2 continued)

The events described in (c) can be described in the β-particle's frame of reference.

(d) For this frame,

(i) identify the moving object. *[1]*

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(ii) state the speed of the moving object. *[1]*

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(iii) calculate the distance travelled by the moving object. *[2]*

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G3. An electron of rest mass m_0 is accelerated through a potential difference V. The total mass of the electron is $3.0\,m_0$.

(a) Determine the momentum of the accelerated electron, as measured in the laboratory frame of reference. *[2]*

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(b) After acceleration, this electron collides with a stationary electron. Discuss whether it is possible for an additional electron-positron pair to be created by this collision. You should consider both the momentum and the energy. *[3]*

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G4. One prediction of Einstein's general theory of relativity is the effect of "gravitational lensing". This effect can be predicted from the principle of equivalence.

(a) State the *principle of equivalence*. *[1]*

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(b) Use the principle to explain *gravitational lensing*. *[4]*

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Option H — Optics

H1. This queston is about the human eye.

The human eye produces images of objects that are placed between the near point and the far point of the eye.

(a) Explain what is meant by

(i) *near point.* *[1]*

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(ii) *far point.* *[1]*

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The optical working of the eye may be modelled as a single lens of variable focal length. In this model, when the eye is focused on a distant object which is not on the principal axis, the eye lens has a focal length of 1.7 cm.

(b) (i) Draw a labelled ray diagram to show how the eye lens forms an image of the distant object. *(**Note**: this is a sketch and does not need to be drawn to scale.)* *[3]*

(This question continues on the following page)

(Question H1 continued)

(ii) State the distance from the lens to the image. *[1]*

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To focus on an object 50 cm away from the eye, the eye lens in the model changes shape to change its focal length. This enables the image distance to remain the same for all object distances.

(c) (i) Determine the new focal length of the eye lens. *[2]*

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(ii) Suggest what change takes place in the shape of the lens in this model. Explain your answer. *[2]*

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(This question continues on the following page)

(Question H1 continued)

In the human eye most of the refraction actually takes place due to the change of medium from air to the cornea (the transparent structure at the front of the eye). The following refractive indices are known.

Material	**Refractive index**
air	1.00
cornea	1.34
water	1.33

(d) (i) Explain what is meant by *refractive index*. *[2]*

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(ii) Use the information to suggest why it is impossible for a person to see objects clearly when swimming underwater. *[2]*

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H2. This question is about waves.

(a) Explain what is meant by

(i) *monochromatic.* *[1]*

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(ii) *coherent.* *[1]*

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(b) The table below compares waves from different sources. The first two rows have been completed for you. Complete the final three rows of the table. *[3]*

	electromagnetic	monochromatic	coherent
light from a laser	Yes	Yes	Yes
sound from a loudspeaker	No	No	No
light from a filament lamp			
γ-rays from a radioactive source			
infra-red rays from the Sun			

(c) State an application of laser light. *[1]*

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H3. A student uses a diffraction grating to view the visible part of the sodium emission spectrum.

(a) Explain how the diffraction grating is able to separate light into component wavelengths. *[3]*

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(b) Sodium light is incident normally on a grating having 6000 lines per centimetre. Calculate the angle at which light of wavelength 589.6 nm will be seen in the first order spectrum. *[2]*

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H4. A student looks at two distant point sources of light. The wavelength of each source is 590 nm. The angular separation between these two sources is 3.6×10^{-4} radians subtended at the eye. At the eye, images of the two sources are formed by the eye on the retina.

(a) State the Rayleigh criterion for the two images on the retina to be just resolved. *[2]*

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(b) Estimate the diameter of the circular aperture of the eye. *[1]*

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(c) Use your estimate in (b) to determine whether the student can resolve these two sources. Explain your answer. *[2]*

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