TC *[66 marks]*

This question is about a converging (convex) lens.

A small object is placed a distance 2.0 cm from a thin convex lens. The focal length of the lens is 5.0 cm.

1a. (i) Deduce the magnification of the lens. *[5 marks]*

(ii) State and explain the nature of the image formed by this lens with the object at this position.

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1b. The object is coloured and the image shows chromatic aberration. Explain what is meant by chromatic aberration. *[2 marks]*

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1c. Describe how the effects of chromatic aberration may be reduced. *[1 mark]*

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This question is about ultrasound scanning.

2a. Outline how ultrasound is generated for medical diagnostic purposes. *[2 marks]*

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2b. When ultrasound of intensity I_0 travels in a medium of acoustic impedance Z_1 and is incident on a medium of acoustic impedance Z_2, the intensity I_R that is reflected at the interface is given by the following equation. *[5 marks]*

$$I_R = \left(\frac{Z_1 - Z_2}{Z_1 + Z_2}\right)^2 I_0$$

The following data are available.

	Speed of sound / m s^{-1}	Density / kg m^{-3}
air	330	1.3
skin	1500	1000

Use the data to deduce why a layer of gel must be used between a transducer and the patient's skin in medical ultrasound imaging.

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2c. In medical scanning, practitioners have the option of using A-scans or B-scans. Distinguish, with reference to the techniques used to produce the scans, between an A-scan and a B-scan. *[3 marks]*

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This question is about optic fibre transmission.

3a. Explain, with reference to the critical angle, what is meant by total internal reflection *[3 marks]*

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3b. In an optic fibre the refractive index of the core is 1.62. The refractive index for the cladding is 1.50. Determine the critical angle for the boundary between the core and the cladding. *[2 marks]*

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3c. State **one** effect of dispersion on a pulse that has travelled along an optic fibre. *[1 mark]*

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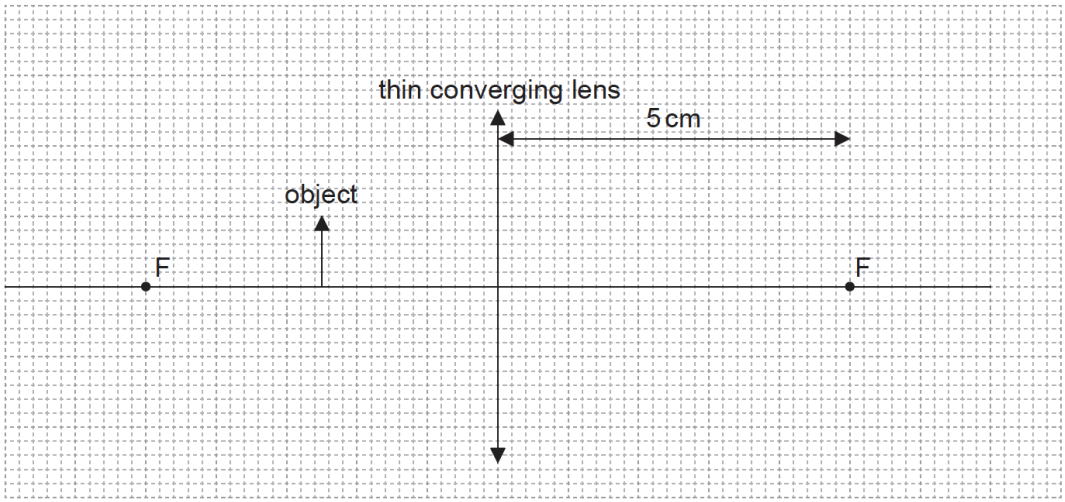
This question is about a thin converging (convex) lens.

The diagram shows an object placed in front of a thin converging lens.



The focal points of the lens are labelled F.

4a. (i) Using the diagram, determine the power of the lens. *[7 marks]*

(ii) On the diagram, construct lines to show how the image of the object is formed by the lens.

(iii) State and explain whether the image is a real image **or** a virtual image.

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4b. Argus uses an astronomical telescope to observe a telecommunications tower. The height of the tower is 82 m and the distance from Argus to the tower is 4.0 km. The image formed by the telescope has an angular diameter of 0.10 rad and is formed at infinity. *[3 marks]*

(i) Determine the angular magnification of the telescope.

(ii) The focal length of the eyepiece is 15 cm. Calculate the focal length of the objective lens.

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This question is about X-rays.

5. (i) X-rays travelling in a medium experience attenuation. State what is meant by attenuation. *[5 marks]*

(ii) Show that the half-value thickness $x_{\frac{1}{2}}$ is related to the attenuation coefficient μ by

$$\mu x_{\frac{1}{2}} = 1\mathrm{n}2$$

(iii) Estimate the fraction of the incident intensity of an X-ray beam that has travelled through 2.0 cm of muscle. The half-value thickness of muscle is 0.73 cm.

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This question is about ultrasound.

6a. Define *acoustic impedance* of a medium. *[1 mark]*

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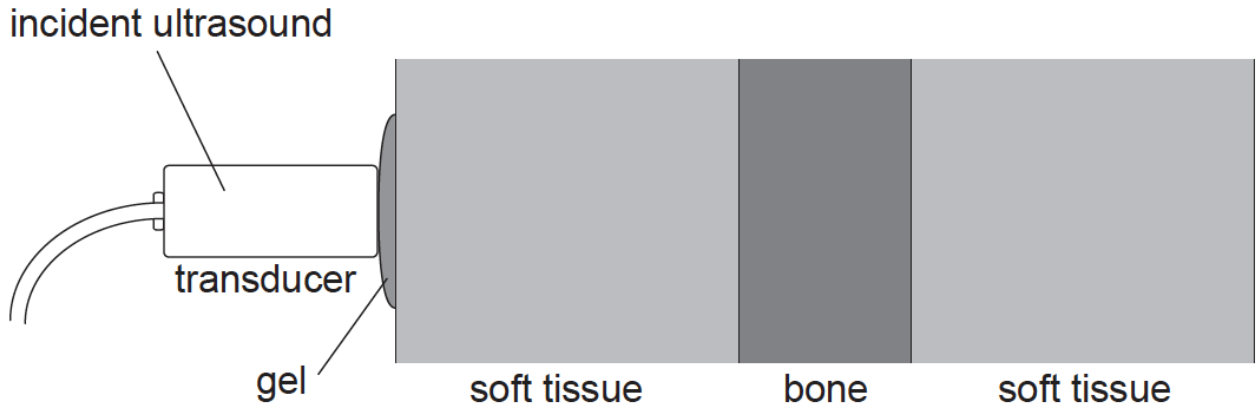
6b. The acoustic impedances for various media are shown in the table. *[6 marks]*

Medium	Acoustic impedance / $kg\,m^{-2}\,s^{-1}$
soft tissue	1.6×10^{6}
gel	1.6×10^{6}
bone	6.1×10^{6}

Ultrasound is incident normally on a layer of soft tissue. Gel is placed between the skin and the transducer.



The fraction of the intensity of ultrasound that is reflected (reflection coefficient) at the boundary of two media of impedances Z_1 and Z_2 is given by the following equation.

$$\left(\frac{Z_2 - Z_1}{Z_2 + Z_1}\right)^2$$

(i) Suggest why the gel allows the ultrasound to enter the soft tissue without any reflection.

(ii) Calculate the reflection coefficient at the soft tissue–bone boundary.

(iii) The soft tissue between the skin and the bone absorbs 60% of the intensity of ultrasound travelling through it. The intensity of ultrasound leaving the transducer is I_0. Determine, in terms of I_0, the intensity of the ultrasound that is reflected back into the transducer from the bone.

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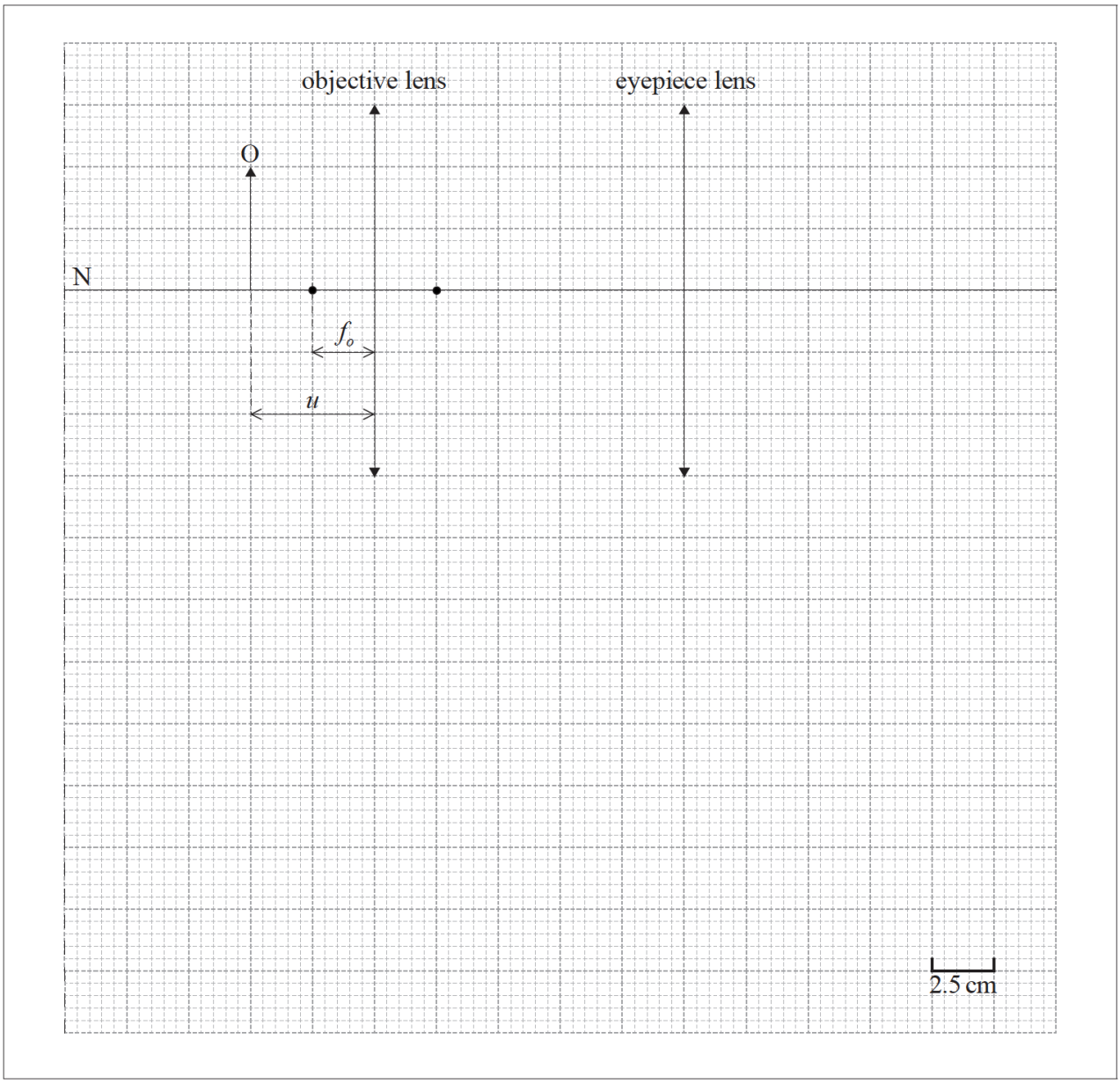
This question is about a compound microscope.

The diagram below shows two thin converging lenses in a compound microscope. The focal length of the objective lens is f_o. The object O is placed at a distance u from the objective lens.



7a. (i) On the diagram above, construct a ray diagram to locate the position of the image formed by the objective lens. Label this image I. *[3 marks]*

(ii) Outline whether the image I is real.

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7b. The compound microscope in (a) is in normal adjustment so that the final image is formed at the near point of an unaided eye. The position of the near point of the eye is located at N. *[6 marks]*

(i) Define *near point*.
(ii) Deduce that the focal length of the eyepiece is around 10.7 cm.
(iii) Estimate the total linear magnification of the microscope.

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This question is about the nature and properties of electromagnetic waves.

8a. Electromagnetic waves propagating in a medium suffer dispersion. Describe what is meant by dispersion. *[2 marks]*

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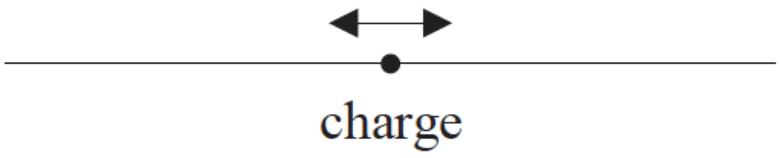
8b. A charge moves backwards and forwards along a wire, as shown in the diagram below. *[2 marks]*



Outline, with reference to the motion of the charge, why electromagnetic radiation is produced by the moving charge.

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This question is about X-rays.

9a. Define *attenuation coefficient*. *[1 mark]*

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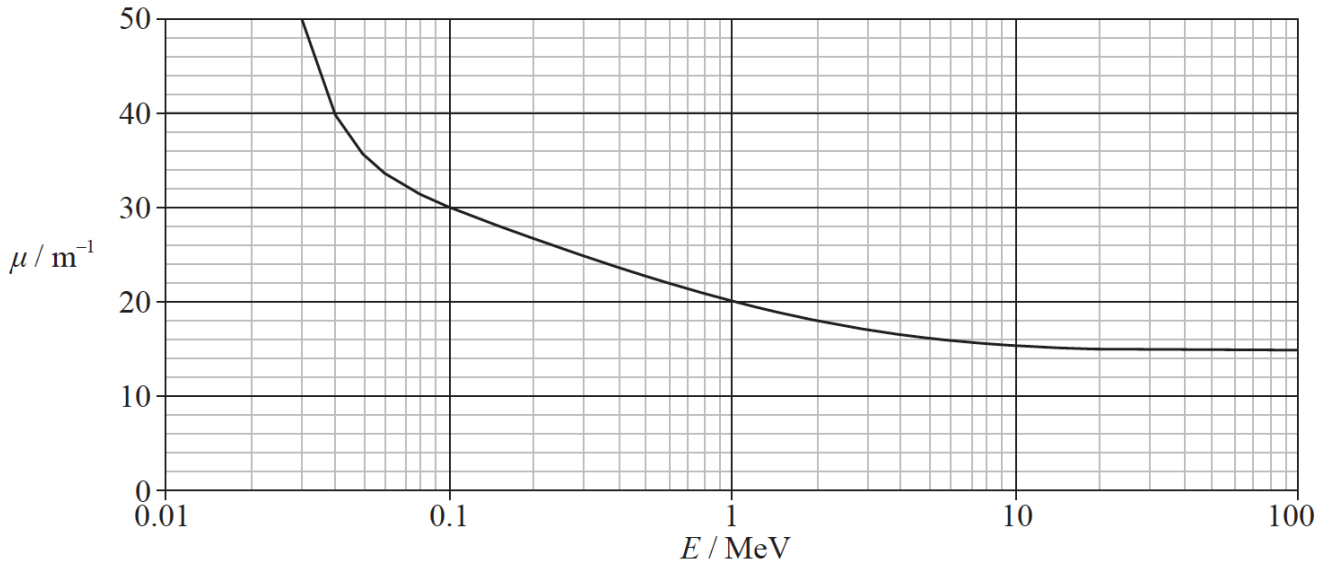
9b. The graph below shows the variation of attenuation coefficient μ with photon energy E for X-rays in an absorbing medium. *[6 marks]*



A beam of X-rays is incident on a sample of the medium with intensity I_0. Using the graph,

(i) determine how far X-rays with energy equal to 0.1MeV travel inside the sample before their intensity reduces to $0.1I_0$.
(ii) predict whether X-rays of energy 10MeV are more penetrating than X-rays of energy 0.1MeV in this medium.