UNIVERSITY OF ABERDEEN:	SESSION 2022/2023
Degree Examination in PX2013	Light Science
Wednesday 7th December 2022	15.00 – 17.00

PLEASE READ CAREFULLY

Answers to descriptive questions should be of length appropriate for the allocated marks.

Answer ALL 5 questions in SECTION A:		**25 marks**
Answer 5 of the 10-mark questions from SECTION B:		**50 marks**
	Total	**75 marks**

PHYSICAL CONSTANTS:

Speed of light in vacuum	**3.0×10^{8} ms^{-1}**
Planck's constant, h	**6.63×10^{-34} J s**
1 eV	**1.603×10^{-19} J**
Refractive index of air	**1.00**

Unless otherwise specified, give numerical answers to three significant figures.

SECTION A – ANSWER ALL FIVE QUESTIONS

1. A ray of light shines at an angle of 19° from air (refractive index n = 1.00) onto a prism (n = 2.17).

(a) Sketch a diagram showing the behaviour of the light ray, marking all appropriate angles and clearly indicating from where they are measured. [2]

(b) What are the angles of the reflected and refracted beams? [1]

(c) State the condition at which the critical angle for a material falls, and derive the equation. [1]

(d) Would a ray of light travelling through the material and arriving at the interface with an incident angle of 28° emerge from the material? Justify your answer. [1]

2. Digital Light Projectors are examples of devices that make use of DMDs.

(a) For what does DMD stand? [1]

(b) What optical principle allows the DMD to function efficiently? [1]

(c) Describe how a DMD produces a colour image on a screen. [3]

3. One method for performing wave addition is the use of phasors, not to be confused with the ones in popular science fiction.

(a) What are phasors? [2]

Assume we have two waves, one of amplitude 5 and the other of amplitude 2, and that the second wave is 30° out of phase with the first.

(b) Sketch this situation, showing how phasors allow us to measure the wave resulting from their addition. (You do not have to precisely determine this wave's parameters.) [2]

(c) Illustrate the maximum and minimum resulting waves if the phase difference of the 2 waves specified in this question varied from 0 to 360° and state the magnitude of the maximum and minimum. [1]

4. An electromagnetic wave travelling in time and space can be represented by the equation:

$$E_0 \sin(kx - \omega t).$$

(a) Starting from the premise that speed (v) is given by: [2]

$$v = \frac{d}{t},$$

where *d* is distance and *t* is time, use the equations for the relationships between angular wavenumber (*k*) and wavelength (λ) and angular frequency (ω) and frequency (*f*) to determine the wave speed equation in terms of ω and k.

(b) A particular light wave has wavelength 542 nm and is travelling in vacuum. The wave's **intensity** is measured as 64. Complete the equation above with all determinable parameters as numerical values. [3]

5. While we can rarely perceive it unaided, light always has a quality called polarisation, which depends on the electric field state of the wave.

(a) What are the equations defining an elliptically polarised wave? [2]

(b) How must these equations be modified to produce linear and circularly polarised waves? [2]

(c) What is pleochroism? [1]

END OF SECTION A

SECTION B – ANSWER ONLY FIVE QUESTIONS

6. The filament bulb was for many years a tool of the wealthy used to light their treasures at night.

(a) How did the modern filament bulb improve on the original carbon filaments? [2]

(b) How does a filament light bulb, incorporating the modifications by Langmuir, work? [4]

(c) What does the Planck Blackbody Law tell us, and what problem in classical physics does it solve? (No mark will be awarded for giving the equation.) [3]

(d) Why are there no green stars? [1]

7. One of Einstein's most elegant and significant achievements was his explanation of the photoelectric effect. For this work, he was awarded the Nobel Prize in Physics, and is often spoken of in the same hushed tones of reverence as Dr. Macpherson.

(a) What four fundamental observations describe the photoelectric effect? [4]

(b) What two ideas did Einstein apply and how did they each contribute to explaining the photoelectric effect? [3]

(c) What is the maximum velocity of photoelectrons released from a metal with a work function of 2.36 eV when light of frequency $1.2\text{x}10^{16}$ Hz is incident on the metal? [3]

8. (a) The Michelson interferometer was the invention of deserving Nobel prize winner Albert Michelson. Draw a diagram of the Michelson interferometer, clearly indicating the paths light takes through the device. [2]

(b) With reference to your diagram, explain how the device produces interference patterns. [3]

(c) Describe the configurations of the Michelson interferometer's mirrors that will produce straight-line fringes and circular fringes. [2]

(d) What is coherence length, and how does it relate to producing interference? What are the two methods of producing interference? [3]

9. Calcite (Iceland spar) is an example of a material that exhibits an unusual optical effect.

(a) What is the name of this effect? [1]

(b) What property of the material causes this effect? [1]

(c) Give a physical description of this effect, including what it does and the appearance of images passing through it, and explaining in detail how the effect arises. [5]

Malus' Law determines the intensity of light transmitted through a sheet of polaroid and is given by:

$$I_1 = I_0 \cos^2 \theta .$$

(d) What is unpolarised light? [1]

(e) What intensity of light would be transmitted through 7 sheets of polaroid each at 11° to the preceding sheet, if the light incident on the first were unpolarised? [2]

10. (a) With the aid of a diagram, list the components of a prism spectrometer, specifying the function of each. [5]

(b) What would substituting a diffraction grating for the prism do to the resulting spectrum? [1]

(c) What is the effect of pressure on the spectral lines produced in the Sun? Why does this happen? [2]

(d) How is an absorption spectrum produced in a lab? [2]

11. Interference and diffraction are related but different phenomena.

(a) What is the fundamental difference between interference and diffraction? [1]

(b) Describe the production of an interference pattern. Ensure you specify the conditions for producing interference, and give an example of an experiment demonstrating this effect. [4]

(c) Using phasors or otherwise, explain how diffraction produces patterns of maxima and minima. [3]

(d) How is the corona around the moon produced? [2]

12. In the Bohr model of the hydrogen atom, electrons exist in discrete energy levels, the value of which can be determined using the equation:

$$E_n = \frac{-13.6}{n^2} eV \, .$$

(a) With reference to the Bohr model, explain the fine spectral lines of hydrogen's emission spectra. [3]

(b) How do these lines relate to the absorption spectra of hydrogen (e.g. the fine dark lines in otherwise continuous spectra, such as that of the Sun) and what are the fundamental differences in the process? [2]

(c) Briefly describe how you would produce an absorption or emission spectra in a lab. [1]

(d) Sketch the first four energy levels for the hydrogen atom, clearly labelling the associated energies in eV. [2]

(e) What wavelength of photon would be emitted in a transition from energy level 3 to 1? [2]

END OF QUESTION PAPER