OCR A A Level Astrophysics 2 spectra and stellar radiation worksheet

35-40 minutes independent practice + 15-20 minutes review | 41 marks

Specification points covered

- 5.5.2(a) Describe electron energy levels in isolated atoms and recognise that bound-state energy levels have negative values.
- 5.5.2(b) Explain emission spectral lines from hot gases as photon emission during electron transitions between discrete energy levels.
- 5.5.2(c) Use $E = hf = hc / \lambda$ to calculate photon energy, frequency or wavelength.
- 5.5.2(d) Recognise that each element has a unique line spectrum and use this to identify elements in stars.
- 5.5.2(e) Describe continuous, emission line and absorption line spectra.
- 5.5.2(f) Use a transmission diffraction grating to determine wavelength using $n\lambda = d \sin \theta$.
- 5.5.2(g) Apply Wien's displacement law λ_{maxT} = constant to estimate stellar surface temperature.
- 5.5.2(h) Apply Stefan's law $L = 4\pi r^2 \sigma T^4$ and combine it with Wien's law to estimate stellar radius.

Arclight Observatory spectrograph commissioning

The Arclight Observatory has installed a transmission-grating spectrograph to analyse light from the fictional star Nereid-T7.

The team first calibrates the instrument with a laboratory gas lamp, then uses line spectra to identify elements and thermal radiation to estimate the star's temperature and radius.

1. Atomic energy levels

1. The ionisation level of an isolated atom is assigned an energy of 0 eV. Explain why the atom's bound electron energy levels have negative values. [1 mark]

2. During calibration, an electron falls from an energy level of -1.85 eV to a level of -4.90 eV. Determine the photon energy in eV and state whether the photon is emitted or absorbed. [2 marks]

3. Use the transition in Question 2 to calculate the wavelength of the photon. Give your answer in both metres and nanometres. Use h = 6.63×10^{-34} J s, c = 3.00×10^{8} m s^{-1} and 1 eV = 1.60×10^{-19} J. [3 marks]

2. Spectral fingerprints

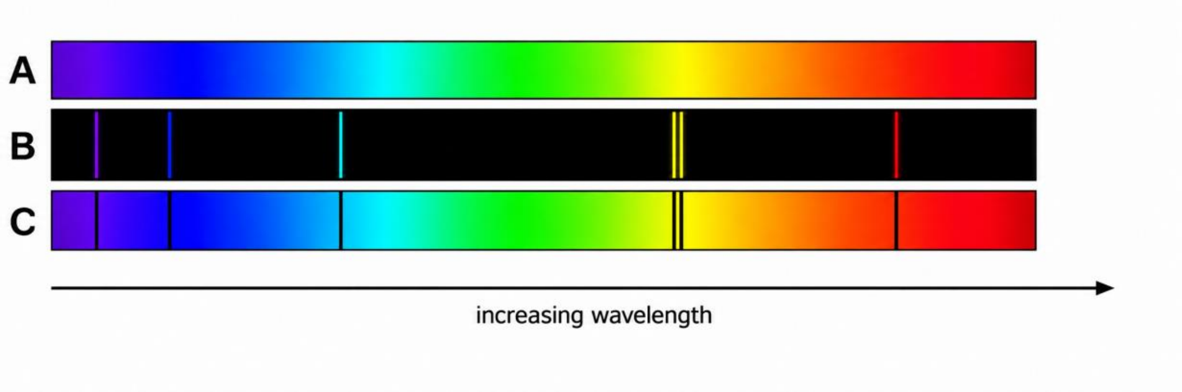

Figure 1: unshifted reference spectra across the visible range

4. Figure 1 shows three spectra recorded while the spectrograph is tested. Identify A, B and C as a continuous spectrum, an emission line spectrum or an absorption line spectrum. [3 marks]

5. The calibration lamp contains a hot, low-pressure gas. Explain why it produces an emission line spectrum rather than every possible wavelength. [2 marks]

6. Light from Nereid-T7 passes through the star's cooler outer atmosphere before reaching the telescope. Explain how the dark lines in its absorption spectrum are produced. [3 marks]

7. After correcting the measured wavelengths for the radial motion of Nereid-T7, its dark lines are at 410.2, 434.0, 486.1, 589.0, 589.6 and 656.3 nm. Laboratory lines are: hydrogen 410.2, 434.0, 486.1 and 656.3 nm; sodium 589.0 and 589.6 nm; helium 447.1, 587.6 and 667.8 nm. Identify the elements detected and explain why a set of matching lines is stronger evidence than a single match. [3 marks]

3. Diffraction grating calibration

8. The calibration grating has 600 lines per millimetre. Calculate the separation d between adjacent grating lines in metres. [2 marks]

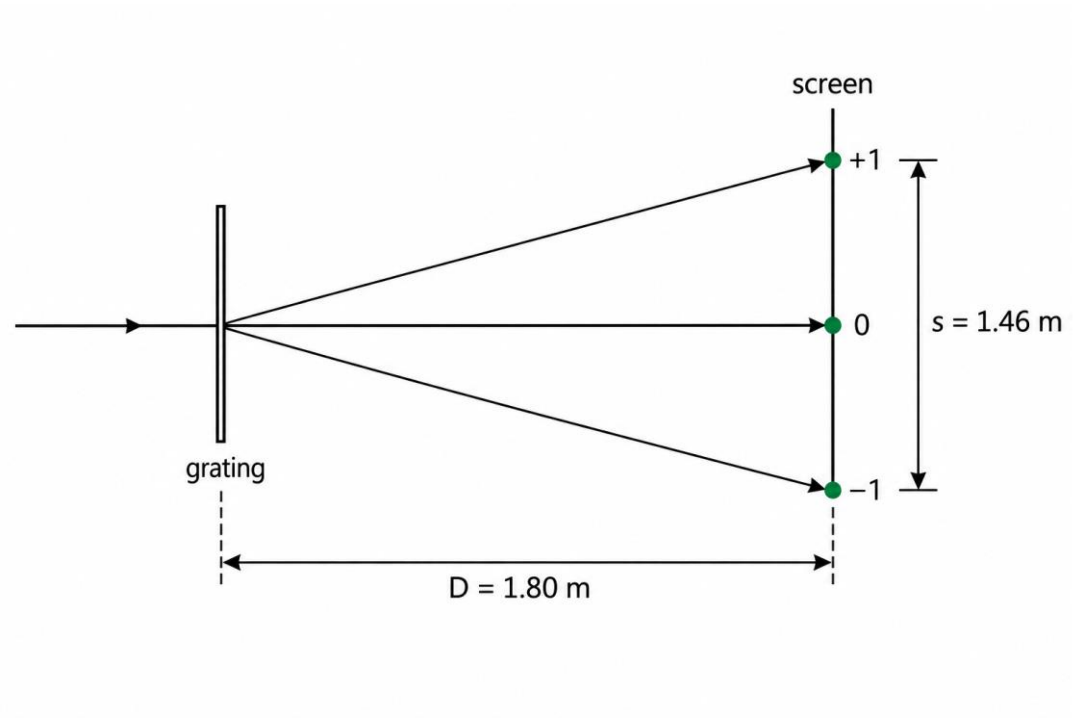

Figure 2: measured first-order diffraction geometry

9. Figure 2 shows the first-order pattern made by one calibration line. Use the figure and your value of d to calculate the wavelength of the light. Give your answer to three significant figures. [4 marks]

3. Diffraction grating calibration continued

10. Use your wavelength from Question 9 to determine the highest possible diffraction order and hence the total number of principal maxima that can be observed, including the central maximum. [2 marks]

11. Describe how the bench arrangement in Figure 2 can be used to determine an unknown wavelength. Include the measurements, how θ is obtained, how the grating spacing is found and one way to reduce the percentage uncertainty. [4 marks]

12. A trainee moves the screen further from the grating and claims that the diffraction angle increases. Evaluate the claim and state one measurement advantage of increasing the grating-screen distance. [2 marks]

4. Stellar temperature and radius

13. The corrected intensity curve for Nereid-T7 has a peak wavelength of 462 nm. Calculate the star's surface temperature using Wien's constant 2.90×10^{-3} m K. [2 marks]

14. The luminosity of Nereid-T7 is 3.40×10^{28} W. Use Stefan's law to calculate its radius. Express the result in metres and as a multiple of the Sun's radius. Use $\sigma = 5.67 \times 10^{-8}$ W m^{-2} K^{-4} and solar radius = 6.96×10^{8} m. [4 marks]

15. A second star has the same surface temperature as Nereid-T7 but nine times its luminosity. Determine the ratio of the second star's radius to the radius of Nereid-T7. [2 marks]

16. A later calibration shows that the true peak wavelength of Nereid-T7 is longer than 462 nm while its luminosity is unchanged. State how the corrected temperature and calculated radius compare with the original values. Explain both changes. [2 marks]