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B.Sc. (Honours) in
Applied Physics & Electronics
Experimental Physics
Applied Mathematics & Physics

**EP434: Research Topics – Paper 4**

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| Time Allowed: TWO hours | Paper contains 5 sections of 2 questions each. Answer ONE question from each of THREE sections. |
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## SECTION A: IMAGING SYSTEMS TECHNOLOGY & APPLICATIONS

Q.1 Describe, with the aid of diagrams, the operation of

(a) a proximity-focused image intensifier employing a microchannel plate, and

(b) a magnetically-focused image intensifier. Include a derivation of the relationship between the magnetic field (B) and the accelerating voltage (V) necessary for focusing action.

If the accelerating voltage is 15 kV and the length of the tube is 6 cm, find the magnetic field necessary for first order focusing. (e/m for an electron = $1.759 \times 10^{11}$ C kg$^{-1}$).

Q.2 Discuss current research in very high energy (VHE) gamma-ray astronomy.
The following headings may be useful:

- Sources of VHE gamma rays
- Extensive air showers
- Cherenkov telescopes
- Image selection techniques

## SECTION B: ASTRONOMY

Q.3 Astronomy is an observational science in which we look for correlations between the observed properties of large numbers of stars, and try to interpret them.

Discuss the importance and the interpretation of the observed correlations between
(a) mass and luminosity, and
(b) surface temperature and luminosity

The main sequence of the Pleiades cluster of stars consists of stars with masses less than 6 $M_o$; the more massive stars having already evolved off the main sequence. Given that the hydrogen-burning lifetime of the Sun is about $10^{10}$ years, estimate the age of the cluster.

Q.4 Describe how a star is held in a process of dynamic equilibrium by the effects of the Virial Theorem.

How does the equilibrium depend upon the adiabatic index of the supporting gas ? What limits does this place on the maximum mass of a super-giant star ?

Estimate the central temperature for a star of 1 $M_O$ due to gravitational collapse. Is this high enough to ignite hydrogen fusion ?

| | | |
|---|---|---|
| $M_O$ | $\approx$ | $2 \times 10^{30}$ kg |
| G | = | $6.67 \times 10^{-11}$ N m$^2$ kg$^{-2}$ |
| proton mass | = | $1.67 \times 10^{-27}$ kg |
| electron mass | = | $9.1 \times 10^{-31}$ kg |
| k | = | $1.38 \times 10^{-23}$ J K$^{-1}$ |
| h | = | $6.63 \times 10^{-34}$ J s |
| electronic charge | = | $-1.6 \times 10^{-19}$ C |

## SECTION C: IMAGING AND OPTICAL METROLOGY

Q.5 Describe the underlying assumptions made for a linear shift invariant system, including ways of characterising its behaviour.

How can this be related to an optical system.

Using the equation for the Huygens-Fresnel principle,

$$V_i(x_i, y_i) = \frac{1}{\lambda j} \iint_A V_a(x_a, y_a) \frac{1}{r} e^{jkr} \cos\theta \, dx_a \, dy_a$$

show that the coherent point spread function is simply the 2D Fourier transform of the pupil function multiplied by a complex constant.

What effect does this have on the process of image formation ?

Q.6 Explain how a hologram can be created by exposing a photographic film to an object wave and a reference wave. Support your explanation with a derivation of the reconstructed object wave.

Explain how this can then be used for the measurement of small-scale deformations to give the equation

$$d \cos\gamma = \frac{n\lambda}{2 \cos\theta}$$

under a real time interferometric holography configuration, with parallel observation and illumination directions. Calculate the spacing between two bright fringes when a bar which was perpendicular to the observation direction for the first exposure is rotated through an angle $\beta$ towards the observer.

If the hologram is detected with a CCD-based imaging system, what are the minimum and maximum values of $\beta$ which can be measured ? How can these limits be improved ?

## SECTION D: SPECTROSCOPY

Q.7 Consider a collection of optically-active centres which are in thermal equilibrium with blackbody radiation characterised by a temperature T. Derive expressions for the Einstein A and B coefficients for transitions between the levels $|1>$ and $|2>$ of the centres.

A beam of radiation with spectral irradiance $I_\nu(0)$ is incident on a medium containing atoms with population densities $N_1$ and $N_2$ in two levels connected by a transition of frequency $\nu_o$. Show that after travelling a distance z through the medium the irradiance is

$$I_\nu(z) = I_\nu(0)\, e^{-\alpha(\upsilon)z}$$

Derive an expression which relates $\alpha$ to the Einstein A coefficient, if it is assumed that $I_\nu$ is independent of $\nu$ over the absorption profile of the transition. Assume that the lineshape function for the transition is $g(\nu)$.

How may the A and B coefficients be measured experimentally ?

Q.8 Answer **two** of the following:

(a) Sketch in a qualitative manner the electronic energy level diagrams for sodium and mercury (or helium) atoms, and explain the differences in the general form of the diagrams.

(b) Describe briefly the various mechanisms which can cause broadening of the optical transitions in a gas. Distinguish between homogeneous and inhomogeneous broadening.

(c) Describe briefly the spectroscopy of optically active centres, such as impurity ions, in solids.

(d) Describe techniques and instrumentation which may be used to study the spectroscopy of optically active species.

# SECTION E: PHYSICS OF THE MIDDLE ATMOSPHERE

Q.9 A *Chapman profile* gives the rate of absorption of monochromatic radiation (q) with altitude (z) in an atmosphere where the concentration of absorber decreases exponentially with altitude. Derive the expression

$$q = q_o \exp [- \{(z/H) + \alpha n_o H e^{-z/H}\}]$$

where $q_o = \alpha n_o I_\infty$.
Assume that *Beer's Law* for the absorption of radiation applies. Explain what the various parameters represent.

Derive expressions for the altitude ($z_m$) at which the rate of absorption (q) is a maximum, and also for the radiant flux density (I) at this altitude.

Q.10 Derive the following expression for variation with altitude (z) of the partial pressure ($p_i$) of a component gas (i) in an isothermal layer of the atmosphere:

$$p_i = p_{o_i} e^{-z/H_i}$$

What is the physical meaning of the scale height $H_I$ ?

On the basis of the above expression, explain in detail, with the aid of an appropriate diagram, how the relative abundances of various component gases vary with altitude in the Earth's atmosphere, above the turbopause.