# Natural Sciences IB: Physics(A)

## Instructions

Time 1.5 hours, Answer **ALL QUESTIONS** Calculators are allowed.

## Question 1

Explain how the $\chi^2$ test can be used to compare theoretical models with data, including a discussion of "degrees of freedom"

In an experiment, a radioactive source is observed through a varying number, $n$ of sheets of material, and the following counts are measured over one second intervals

| number of sheets | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| counts in 1s | 103 | 80 | 79 | 71 | 50 | 52 | 46 | 51 |

The exact nature of the material is unknown, but there are two possibilities, each of which predict a count rate of

$$N_0 e^{-na}$$

where $N_0 = 104.5$ counts $s^{-1}$, has been determined from a 900 s long integration observation with no sheets of material (i.e. $n = 0$ ) and $a$ could be either 0.15 or 0.19 depending on the material.

Explain why the value of $N_0$ is accurately known compared with the counts in 1 s given above

Carry out a $\chi^2$ test to see which value of $a$ is preferred

Plot a suitable graph of the data, including appropriate error bars and the preferred model predictions. Use this to suggest how the model might be improved.

# Question 3

Explain the conditions under which Fresnel diffraction applies

Show that the complex amplitude of the radiation received at an on-axis point a distance $z$ from an annular aperture of radius $r(\ll z)$ and thickness dr illuminated normally by a parallel beam of wavelength $\lambda$ is given by

$$d\psi \propto K \exp\left(\frac{i\pi r^2}{\lambda z}\right) 2\pi r dr$$

where $K$ is an obliquity factor

Explain with the aid of a phasor diagram how this expression can be used to derive the amplitude received when the annulus is replaced with a circular aperture of radius $R$. Include in your discussion a definition of Fresnel half-period zones and show that the radius of the $n^{th}$ such zone is given by $\sqrt{n\lambda z}$

A circular aperture 3.8 mm in diameter is illuminated normally with a parallel beam of white light containing radiation over the wavelength range $\lambda = 400$ nm to 700 nm. What wavelengths are missing from the light received on-axis 1 m away from the aperture?