DEVIL PHYSICS
THE BADDEST CLASS ON CAMPUS

IB PHYSICS

TSOKOS LESSON 9-4 RESOLUTION

Essential Idea:

- Resolution places an absolute limit on the extent to which an optical or other system can separate images of objects.

Nature Of Science:

- Improved technology:
  - The Rayleigh criterion is the limit of resolution. Continuing advancement in technology such as large diameter dishes or lenses or the use of smaller wavelength lasers pushes the limits of what we can resolve.

International-Mindedness:

- Satellite use for commercial and political purposes is dictated by the resolution capabilities of the satellite.

Theory Of Knowledge:

- The resolution limits set by Dawes and Rayleigh are capable of being surpassed by the construction of high quality telescopes.
- Are we capable of breaking other limits of scientific knowledge with our advancing technology?

Understandings:

- The size of a diffracting aperture
- The resolution of simple monochromatic two-source systems

Applications And Skills:

- Solving problems involving the Rayleigh criterion for light emitted by two sources diffracted at a single slit
- Resolvance of diffraction gratings

Guidance:

- Proof of the diffraction grating resolvance equation is not required

Data Booklet Reference:

$$\theta = 1.22 \frac{\lambda}{b}$$

$$R = \frac{\lambda}{\Delta\lambda} = mN$$

Utilization:

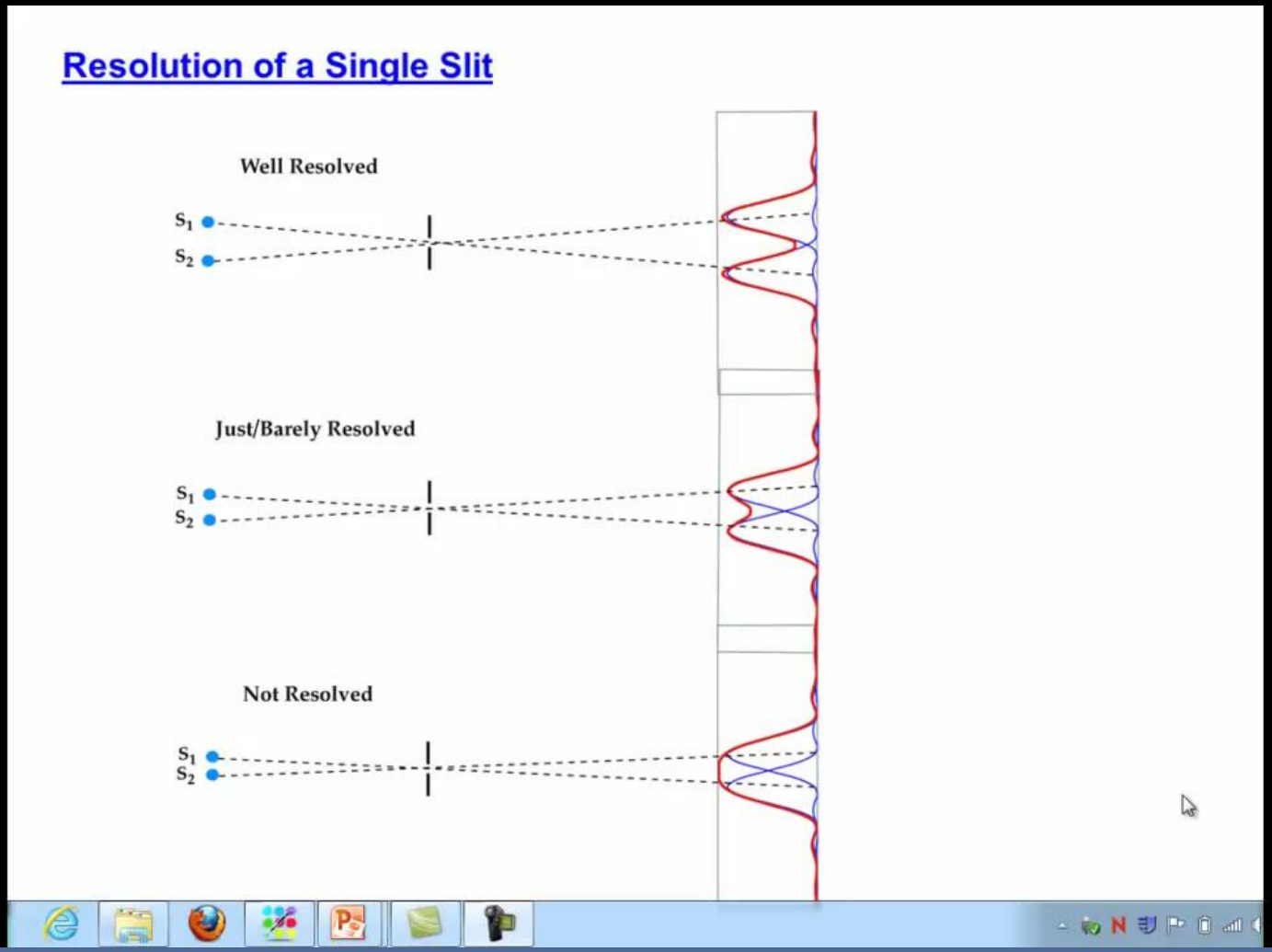
- An optical or other reception system must be able to resolve the intended images. This has implications for satellite transmissions, radio astronomy and many other applications in physics and technology (see Physics option C)
- Storage media such as compact discs (and their variants) and CCD sensors rely on resolution limits to store and reproduce media accurately

Aims:

- Aim 3: this sub-topic helps bridge the gap between wave theory and real-life applications
- Aim 8: the need for communication between national communities via satellites raises the awareness of the social and economic implications of technology

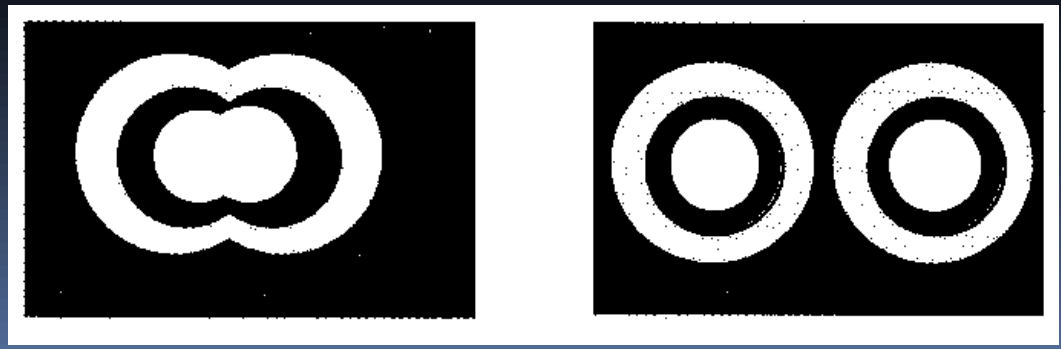
Reading Activity Questions?

Introductory Video: Rayleigh Criteria



Rayleigh Criterion

- Diffraction is a way of life
- Diffraction occurs in all lenses, including your eye
- In diffraction there are maxima and minima
- In order to see two objects as two separate objects, you need to separate the maxima for those objects

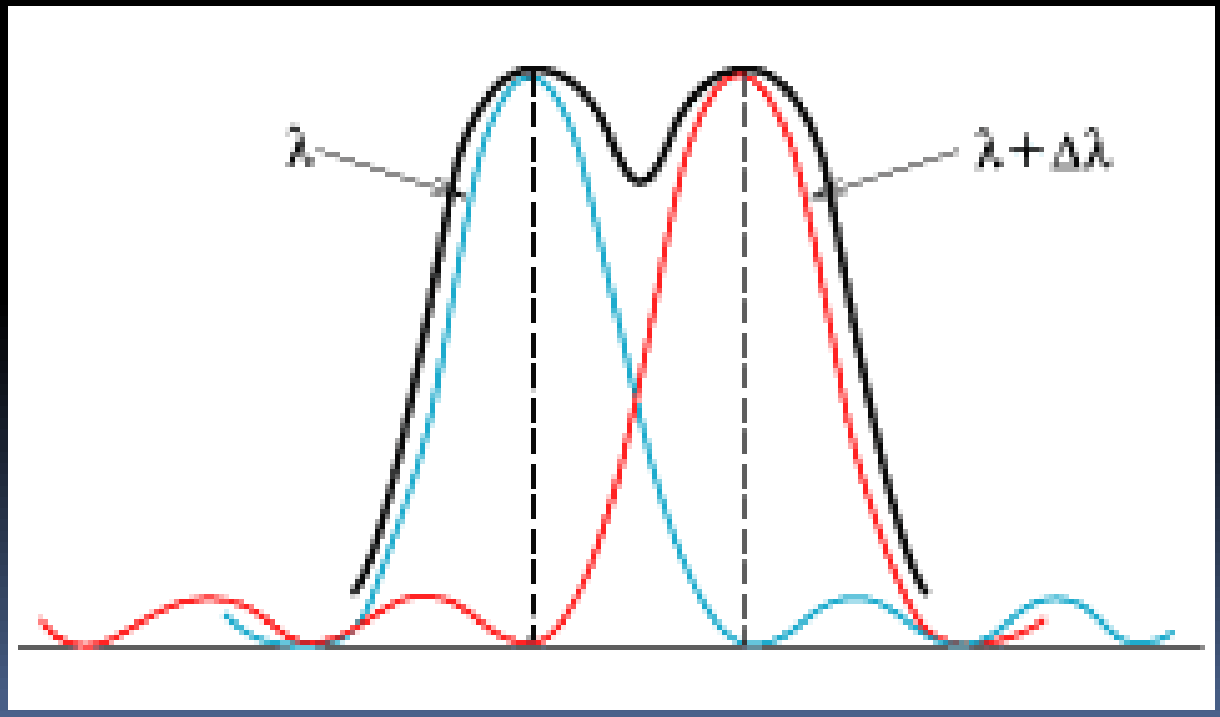


Rayleigh Criterion

- The Rayleigh criterion gives the minimum separation angle in which the two objects can just be resolved

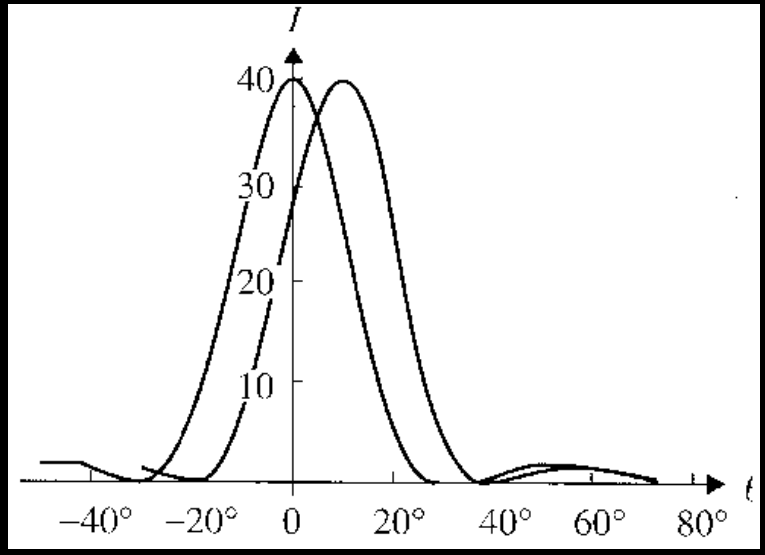
Rayleigh Criterion

- ***The criterion is that the central maximum of one of the sources is formed at the first minimum of the second***

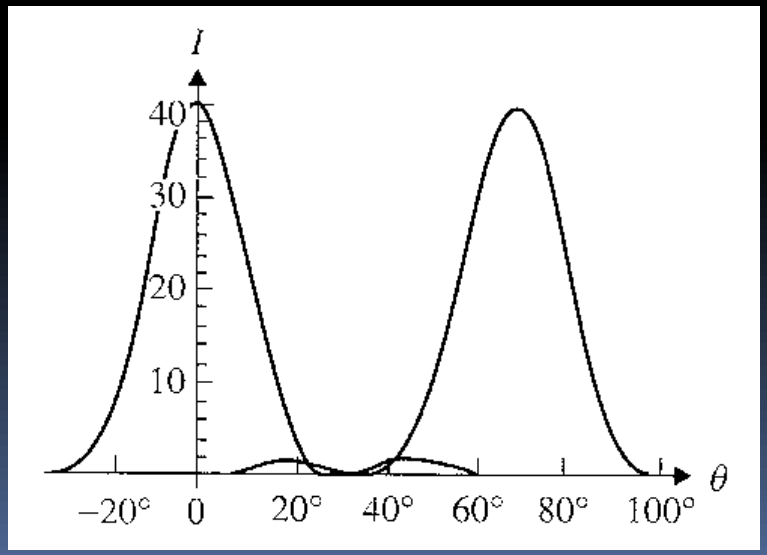


Rayleigh Criterion

- Two unresolved sources



- Two well-resolved sources



Rayleigh Criterion

- In diffraction, the first minima for a ***rectangular*** slit of width ***b*** occurs at:

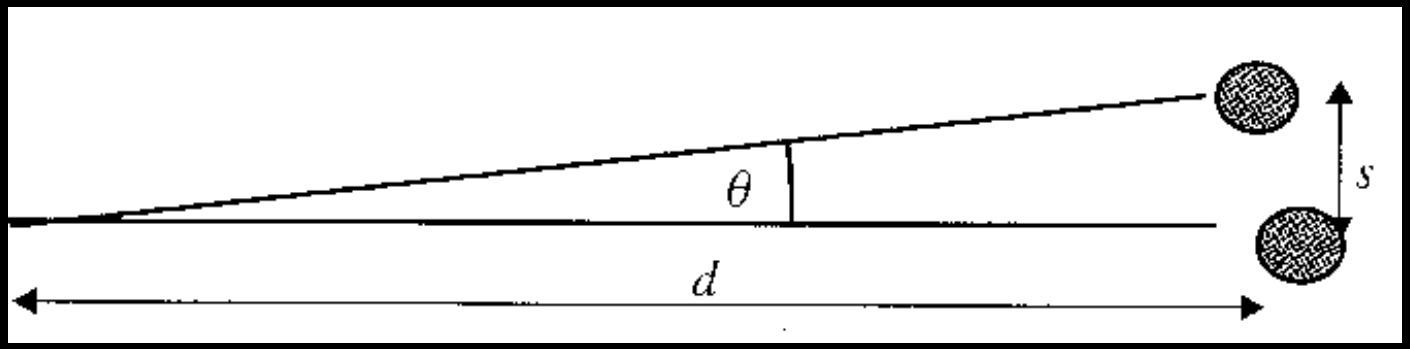
$$\theta = \frac{\lambda}{b}$$

- The first minima for a ***circular*** slit of diameter ***b*** occurs at:

$$\theta = 1.22\frac{\lambda}{b}$$

- ***Therefore, objects can be resolved if their separation angle exceeds θ (in radians!)***

Rayleigh Criterion

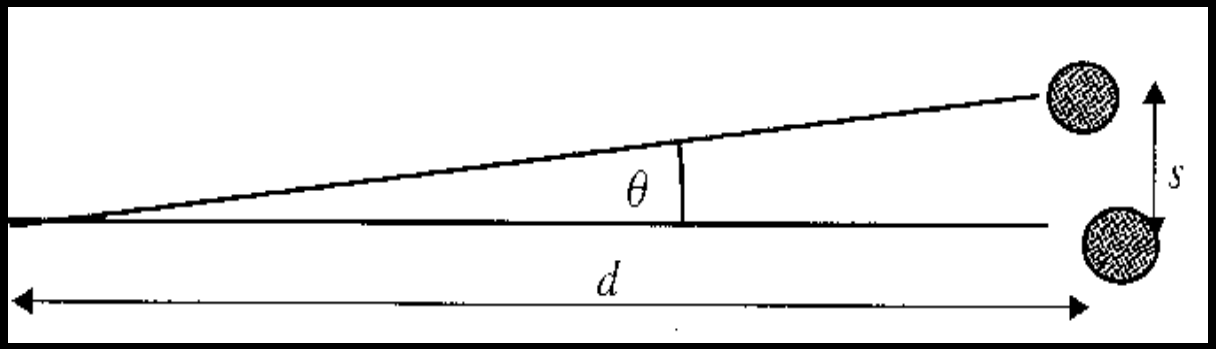


- If two objects are separated by a distance s and their distance from the observer is d, then their angular separation (in radians) is given by

$$\theta = \frac{s}{d}$$

$$\sin\theta \approx \theta$$

Rayleigh Criterion



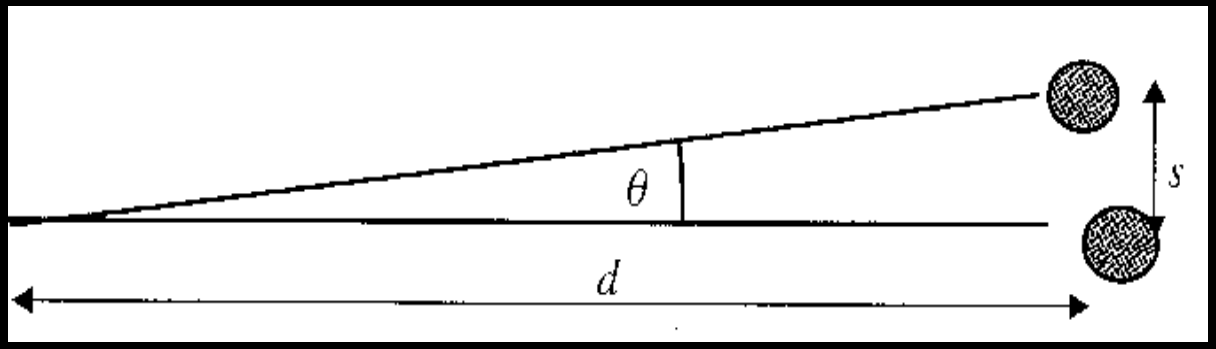
- Rectangular opening (aperture)

$$\theta = \frac{\lambda}{b}$$

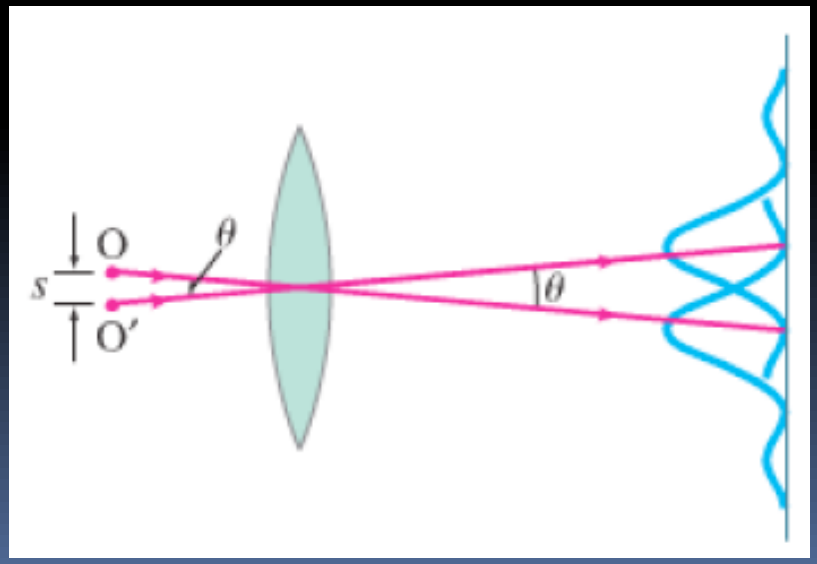
$$\theta = \frac{s}{d}$$

$$\frac{\lambda}{b} = \frac{s}{d}$$

Rayleigh Criterion



- Circular opening (aperture)



$$\theta = 1.22\frac{\lambda}{b}$$

$$\theta = \frac{s}{d}$$

$$\frac{1.22\lambda}{b} = \frac{s}{d}$$

Sample Problem

The camera lense of a spy satellite orbiting at 200km has a diameter of 35 cm. What is the smallest distance this camera can resolve on the surface of the earth? (Assume a wavelength of 500nm)

Sample Problem

The camera lense of a spy satellite orbiting at 200km has a diameter of 35 cm. What is the smallest distance this camera can resolve on the surface of the earth? (Assume a wavelength of 500nm)

$$\theta = \frac{s}{d} = 1.22\frac{\lambda}{b}$$

$$s = 1.22\frac{\lambda d}{b} = \frac{(1.22)(5x10^{-7})(2x10^{5})}{.35}$$

$$s = 0.35m$$

Microscopes

- In microscopes, the object is in focus when it is at the focal length of the lens (hence the name)

$$\theta = \frac{s}{f}$$

- The condition for resolution then becomes,

$$\theta = \frac{s}{f} = 1.22\frac{\lambda}{b}$$

$$s = 1.22\frac{\lambda f}{b}$$

Microscopes

- In practice, f is of the same order of magnitude as b so $f \approx b$
- Therefore, in terms of order of magnitude, $s \approx \lambda$
- ***To resolve a small object of size s, the wavelength of light used, λ, must be the same order of magnitude as s or smaller***

Electron Microscope

- In order to see an object as small as 0.01nm, we can't use visual light
- However, we can make use of the wave nature of electrons

Electron Microscope

- Sample Application:
  - We excite an electron to 10^5 eV = 1.6 x 10^{-14} J (kinetic energy)
  - The mass of an electron is 9.1 x 10^{-31} kg

$$E_K = \frac{p^2}{2m}$$

$$p = \sqrt{E_K 2m} = 1.71x10^{-22}\, N \cdot s$$

Electron Microscope

- Sample Application:
  - We excite an electron to 10^5 eV = 1.6 x 10^{-14} J (kinetic energy)
  - The mass of an electron is 9.1 x 10^{-31} kg

$$p = \sqrt{E_K 2m} = 1.71x10^{-22}\, N \cdot s$$

$$\lambda = \frac{h}{p} = \frac{6.63x10^{-34}}{1.71x10^{-22}} = 4x10^{-12}$$

Electron Microscope

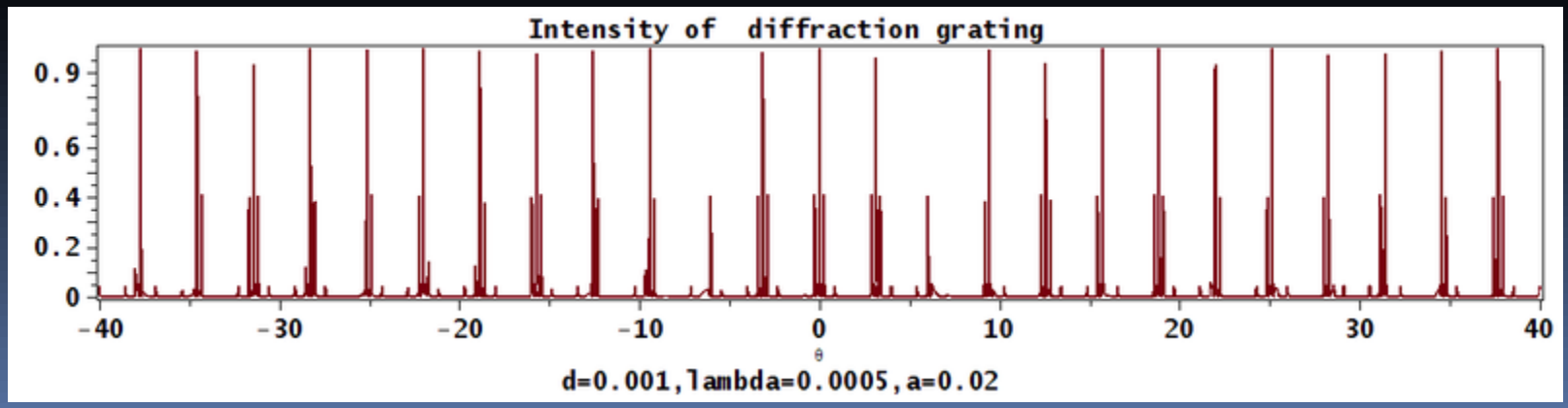
- Sample Application:
  - We excite an electron to 10^5 eV = 1.6 x 10^{-14} J (kinetic energy)
  - The mass of an electron is 9.1 x 10^{-31} kg

$$\lambda = \frac{h}{p} = \frac{6.63x10^{-34}}{1.71x10^{-22}} = 4x10^{-12}$$

  - To resolve particles as small as 10^{-18}m, electrons need energy in excess of 1000 GeV – hence the need for particle accelerators!

Diffraction Grating Resolution

- Diffraction gratings are supposed to resolve two different wavelengths in a spectrum that are close to each other
- Because the wavelengths are close to each other, the angle that separates them is small
- *Houston, do we have a problem?*



Diffraction Grating Resolution

- Resolving power, *R*

$$R = \frac{\lambda_{avg}}{\Delta\lambda}$$

  - λ_{avg} *is the average of two wavelengths*
  - $\Delta\lambda$ *is the difference between the two wavelengths*
- A larger resolving power means the smaller the difference between the two wavelengths can be

Diffraction Grating Resolution

- Resolving power

$$\frac{\lambda_{avg}}{\Delta\lambda} = mN$$

  - *m is the order at which the lines are observed*
  - *N is the total number of slits in the grating*
- A larger resolving power means the smaller the difference between the two wavelengths can be

Diffraction Grating Resolution

- Resolving power

$$\frac{\lambda_{avg}}{mN} = \Delta\lambda$$

- This gives the smallest difference between two wavelengths that can be resolved
- The smaller the difference, the larger the number of gratings

Aims:

- Aim 3: this sub-topic helps bridge the gap between wave theory and real-life applications
- Aim 8: the need for communication between national communities via satellites raises the awareness of the social and economic implications of technology

Utilization:

- An optical or other reception system must be able to resolve the intended images. This has implications for satellite transmissions, radio astronomy and many other applications in physics and technology (see Physics option C)
- Storage media such as compact discs (and their variants) and CCD sensors rely on resolution limits to store and reproduce media accurately

Applications And Skills:

- Solving problems involving the Rayleigh criterion for light emitted by two sources diffracted at a single slit
- Resolvance of diffraction gratings

Data Booklet Reference:

$$\theta = 1.22 \frac{\lambda}{b}$$

$$R = \frac{\lambda}{\Delta\lambda} = mN$$

Understandings:

- The size of a diffracting aperture
- The resolution of simple monochromatic two-source systems

Essential Idea:

- Resolution places an absolute limit on the extent to which an optical or other system can separate images of objects.

QUESTIONS?

Homework

#27-35