Resolution – Not just for the New Year

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Date Created: 07/31/2013
Subject: Physics
Grade Level: 11-12
Standards:
- Standard 1: M1.1 Use algebraic and geometric representations to describe and compare data.
- Standard 6: 2.4 Compare predictions to actual observations, using test models.
- Standard 4 Major Understanding:
  - 4.3l Diffraction occurs when waves pass by obstacles or through openings. The wavelength of the incident wave and the size of the obstacle or opening affect how the wave spreads out.

Schedule: Two 45-minute class periods (one for background and one for activity)

Description:

Students will determine the resolution of their eye through the use of a resolution chart and simple geometry. They will then compare this to the resolution angle predicted by the Rayleigh Criterion.

Objectives:

- Students will be able to
  - Experimentally calculate the angular resolution of their eye
  - Use the Rayleigh Criterion to predict the angular resolution of their eye
  - Understand the connection between resolution and optical instruments such as telescopes and microscopes

Vocabulary:

- Diffraction
- Resolution
- Rayleigh Criterion
- Aperture
- Wavelength

Materials:

- Resolution eye chart (proved at end of lesson)
- Meterstick
- Centimeter ruler

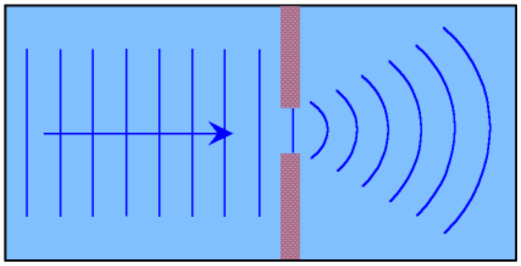
Safety:

Be careful when measuring the diameter of the pupil

Always follow safe laboratory procedures

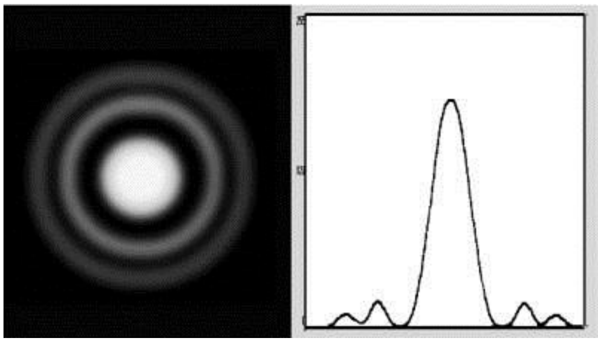
Science Content for the Teacher:

When light passes though an opening it is diffracted.



http://www.smkbud4.edu.my/Data/sites/vschool/phy/wave/diffraction.htm

When light passes through a circular opening, or aperture, it produces a pattern of concentric rings around a central bright spot, called the Airy disk. This Airy pattern can also be represented graphically:



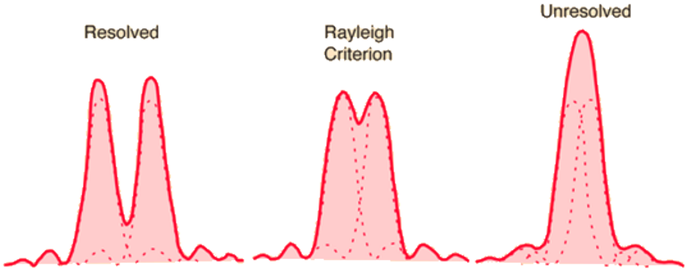
http://www.astro.ljmu.ac.uk/courses/phys134/pic/scope/airydisk.jpg

Circular apertures can include the pupil of the eye, a camera lens, and a telescope.
The angle at which the first minimum is observed is found to be:

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

Where λ is the wavelength of light and b is the aperture opening.

When two sources of light are observed, their diffraction patterns can overlap:



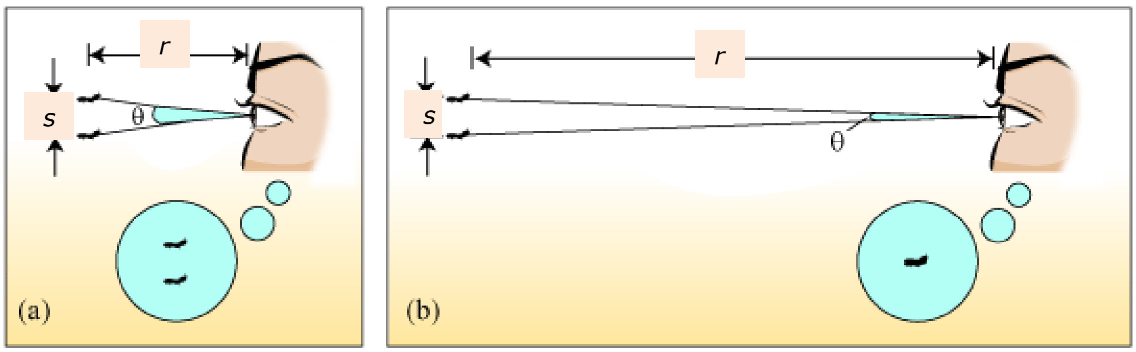
http://hyperphysics.phy-astr.gsu.edu/hbase/phyopt/imgpho/rayc.gif

We consider something to be resolved when we can just distinguish the two sources of light.

According to the Rayleigh Criterion, two images will be just resolvable when the first maximum of one pattern falls on the first minimum of the other pattern. Therefore, the smallest angle that the two sources can be distinguished apart from will be found by using the same equation above. It is important to note that the angle of resolution is then directly related to the wavelength and indirectly related to the aperture size; i.e. the larger the wavelength the larger the angle – which means objects would need to be further apart to be resolved; and the larger the aperture and smaller the angle, which means large apertures give better resolution.

This angle can also be related to the distance from the object (r) and the distance between them (s) through a simple geometric relationship:

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



http://www.hk-phy.org/atomic_world/tem/tem01_e.html

Note how distance can affect the ability to resolve objects.

Classroom Procedure:

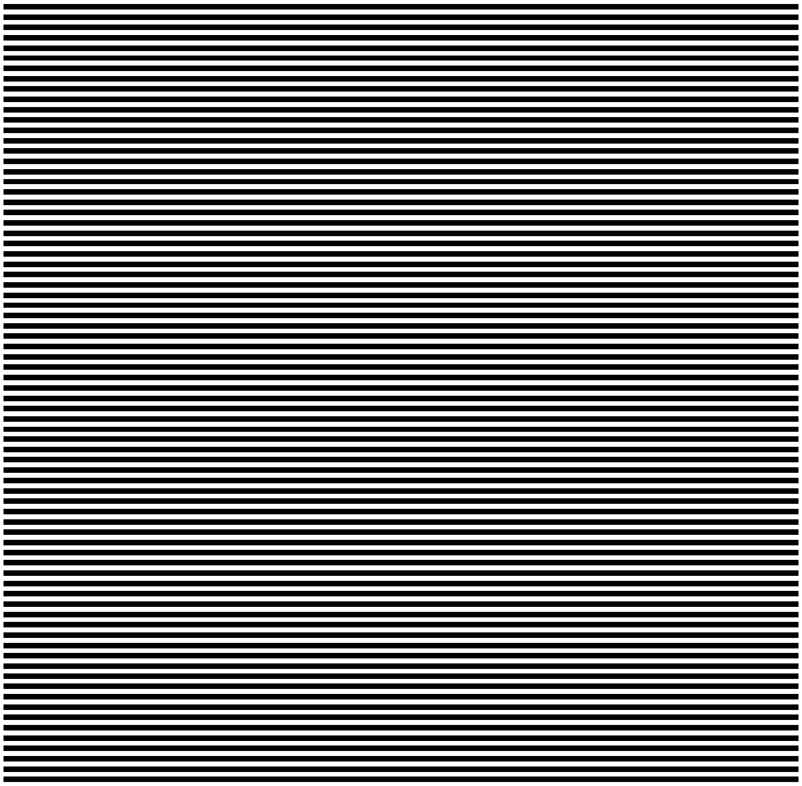
1. Print appropriate number of copies of the attached resolution chart to allow students to work in pairs. I suggest removing the header and footer so students cannot use them as visual clues, and attaching it to a rigid piece of cardboard for stability.
2. Have students complete the attached worksheet, helping groups when necessary.

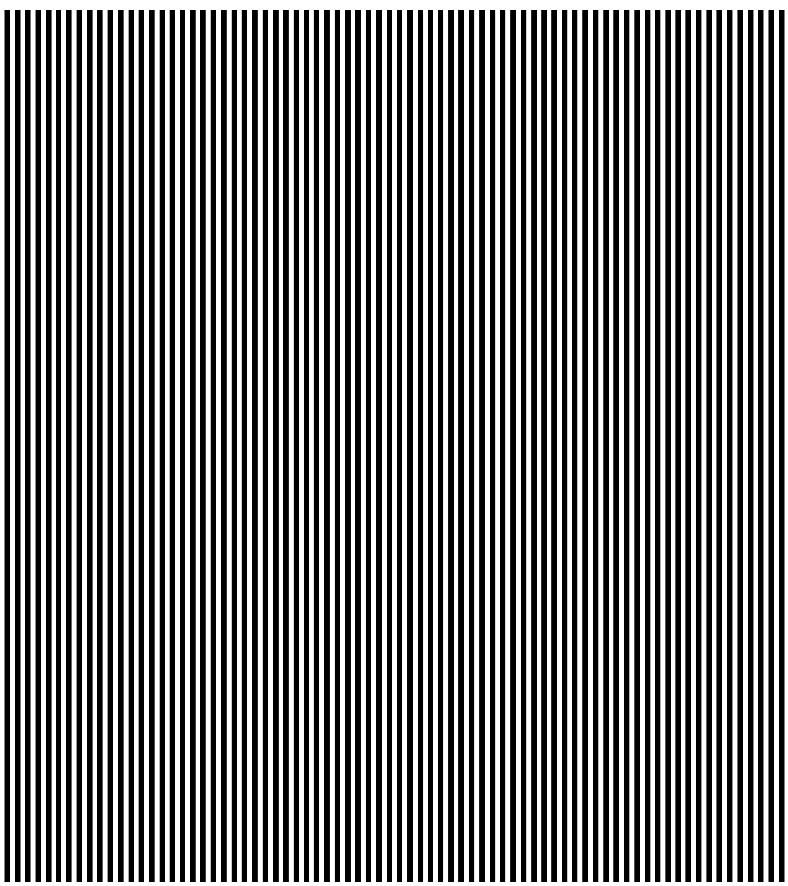
Assessment:

Students will be asked to complete resolution questions at the end of the worksheet on their own.

Acknowledgements:

Cornell Center for Materials Research
Nev Singhota
CCMR Facility Managers
Kaleigh M. Muller





1.8 mm between black bar centers

Name________________________

Date_________________________

Resolution – Not just for the New Year!

Pre-Lab Questions:

1. Define resolution

2. With the aid of a diagram, define the Rayleigh Criterion

Materials:

Meterstick, centimeter ruler, resolution chart

Procedure:

Part A – Angular Resolution of your eye using Geometry:

1. Mark with tape a spot for your partner to stand – this is your zero position. Ensure that you have several yards in front of this point to work with.
2. Give your partner hold up the resolution chart. Beyond a certain distance, you will be unable to resolve the vertical bars from the horizontal bars.
3. Stand far enough away from your partner that you cannot resolve the bars and have your partner hold up the chart in an orientation unknown to you, with either the horizontal or vertical bars on your right.
4. Slowly approach your partner, and when you think you can tell if the bars on the right are horizontal or vertical, stop and indicate to your partner which side you think the horizontal bars are on.
5. If you are correct, place a piece of tape on the floor to indicate the distance at which you were able to resolve correctly. Back up, turn away, and have your partner randomly rearrange the chart and repeat the procedure several more times. If you are not correct, back up, turn away, and have your partner randomly rearrange the chart and repeat the procedure.

6. Continue the process until you have a maximum distance at which you can consistently identify the bars correctly. Measure and record this distance:

   r = ____________________________

7. The separation between the bars (*s*) is marked on the chart. Find the angle at which you can consistently resolve using $\theta = s/r$. Calculate and record this angle. Make sure your units match!

   θ = ___________________________________

8. Repeat this procedure for your partner.

Part B – Angular resolution using the Rayleigh Criterion:

1. In the normal light conditions that you performed part A, have your partner use the centimeter ruler to measure the diameter of your pupil. This is your aperture opening b. Record it here:

   b = _____________________________

2. Taking the wavelength of light to be 550nm, use the Rayleigh Criterion to calculate your angular resolution. Record it here. Make sure your units match!

   θ = _______________________________

Questions:

1. How close were your two angular values? If the Rayleigh Criterion is the 'perfect' eyesight, what percent error do you have?

2. What do you think could have caused the differences? Think of any assumptions that were made and possible sources of error.

3. Two stars are 20 light years away and can just be resolved using a telescope with an aperture of 55cm. How far apart are the stars? Take the wavelength of light as 450nm and 1 light year = 9.46×10^{15} m.

4. A radio telescope wants to resolve a signal with a wavelength of 3×10^{-1} m from two stars that are 15 light years away and 5.5×10^{-2} light year apart. How large does the dish aperture need to be?

5. Electron Microscopes:

   For a 20 keV electron microscope, the velocity can be determined using:

$$KE = \frac{1}{2} mv^2$$

   Where $m = 9.11 \times 10^{-31}$ kg and $1eV = 1.6 \times 10^{-19}$ J.

v = ______________________________

The wavelength of an electron is found using the de Broglie wavelength:

$$\lambda = \frac{h}{mv}$$

Where *h* is Plank's constant 6.63 x 10^{-34} Js, *m* is 9.11 x 10^{-31} kg. Find the electron wavelength.

λ = ____________________________

6. According to question 6 and what you know about the wavelengths of visible light, which microscope would have a higher resolving power - an electron microscope or visible light microscope? Why?