A Content Secondary Science Newsletter from the
Southern Nevada Regional Professional Development Program

Science Dissected

Nature of Light
Model-Evidence Link Diagram (MEL)

The dispute over the nature of light dates back centuries. Prominent scientists have contended over light's behavior as a wave or a particle, arguing that only one could be correct. In fact, only in the 1900s did scientist begin to fully accept the idea that light could act as both.

The duality of light can be examined in all science disciplines. This issue of Science Dissected provides an instructional resource for teachers to present students with the opportunity to examine several pieces of evidence compiled about the behavior of waves and particles and critically evaluate two models of the nature of light;

Model A: Light demonstrates the properties of a wave .

Model B: Light demonstrates the properties of a particle.

Evidence #1: Waves exhibit the Doppler Effect.

Evidence #2: Waves reflect, refract and diffract.

Evidence #3: Waves travel trough a medium.

Evidence #4: Particles exhibit both diffuse and specular reflection.

Additional Evidence Ideas…

The use of particles of light in photosynthesis.

The use of particles of light for photovoltaic cells

The following is a suggestion for using this MEL with students:

1. Hand out the Nature of Light Model Evidence Link Diagram (page 1). Instruct students to read the directions, descriptions of Model A and Model B, and the four evidence texts presented.
2. Handout the four evidence text pages (pages 3-7).
3. Instruct students to carefully review the Evidence #1 text page (page 3-4), then construct two lines from Evidence #1; one to Model A and one to Model B. Remind students that the shape of the arrow they draw indicates their plausibility judgment (potential truthfulness) connection to the model.
4. Repeat for Evidence #2-4 (pages 5-7).
5. Handout page 2 for the students to critically evaluate their links and construct understanding.

Once students have completed page 2, they can then engage in collaborative argumentation as they compare their links and explanations with that of their peers. Students should be given the opportunity to revise the link weighting during the collaborative argumentation exercise. If time permits, have students reflect on their understanding of the nature of light and create questions that they might explore in the future.

Archived Issues of Science Dissected, http://www.rpdp.net/link.news.php?type=sciencedis. Instructional Resource resulting from Plausibility, It's All About Connecting the Models Workshop co-sponsored by CPDD and SNRPDP Science March 6, 2012

Written by: Jonathan Guerin

Name:____ ____________________ **Period:**________________

Directions: draw two arrows from each evidence box. One to each model. You will draw a total of 8 arrows.

Key:

- The evidence **supports** the model
- The evidence **STRONGLY supports** the model
- The evidence **contradicts** the model (shows its wrong)
- The evidence has **nothing to do with** the model

Standard: P.12.C.1

Evidence #1
Waves exhibit the Doppler Effect.

Model A
Light demonstrates the properties of a wave.

Evidence #3
Waves travel through a medium.

Evidence #2
Waves reflect, refract, and diffract.

Model B
Light demonstrates the properties of a particle.

Evidence #4
Particles exhibit specular and diffuse reflection.

Provide a reason for three of the arrows you have drawn. **Write your reasons for the three most interesting or important arrows.**

A. Write the number of the evidence you are writing about.
B. Circle the appropriate descriptor (**strongly supports | supports | contradicts | has nothing to do with**).
C. Write the letter of the model you are writing about.
D. Then write your reason.

1. Evidence # ____ strongly supports | supports | contradicts | has nothing to do with Model _____ because:

2. Evidence # ____ strongly supports | supports | contradicts | has nothing to do with Model _____ because:

3. Evidence # ____ strongly supports | supports | contradicts | has nothing to do with Model _____ because:

4. Circle the plausibility of each model. [Make two circles. One for each model.]

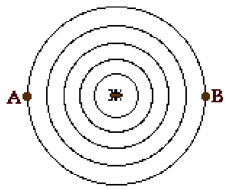
	Greatly implausible (or even impossible)									Highly Plausible
Model A	1	2	3	4	5	6	7	8	9	10
Model B	1	2	3	4	5	6	7	8	9	10

5. Circle the model which you think is correct. [Only circle one choice below.]

Very certain that Model A is correct	Somewhat certain that Model A is correct	Uncertain if Model A or B is correct	Somewhat certain that Model B is correct	Very certain that Model B is correct

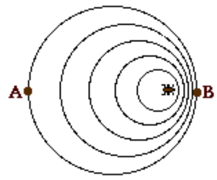
EVIDENCE 1: WAVES EXHIBIT THE DOPPLER EFFECT.

Suppose that there is a happy bug in the center of a circular water puddle. The bug is periodically shaking its legs in order to produce disturbances that travel through the water. If these disturbances originate at a point, then they would travel outward from that point in all directions. Since each disturbance is traveling in the same medium, they would all travel in every direction at the same speed. The pattern produced by the bug's *shaking* would be a series of concentric circles as shown in the diagram at the right. These circles would reach the edges of the water puddle at the same frequency. An observer at point A (the left edge of the puddle) would observe the disturbances to strike the puddle's edge at the same frequency that would be observed by an observer at point B (at the right edge of the puddle). In fact, the frequency at which disturbances reach the edge of the puddle would be the same as the frequency at which the bug produces the disturbances. If the bug produces disturbances at a frequency of 2 per second, then each observer would observe them approaching at a frequency of 2 per second.



A stationary bug producing disturbances in water.

Now suppose that our bug is moving to the right across the puddle of water and producing disturbances at the same frequency of 2 disturbances per second. Since the bug is moving towards the right, each consecutive disturbance originates from a position that is closer to observer B and farther from observer A. Subsequently, each consecutive disturbance has a shorter distance to travel before reaching observer B and thus takes less time to reach observer B. Thus, observer B observes that the frequency of arrival of the disturbances is higher than the frequency at which disturbances are produced. On the other hand, each consecutive disturbance has a further distance to travel before reaching observer A. For this reason, observer A observes a frequency of arrival that is less than the frequency at which the disturbances are produced. The net effect of the motion of the bug (the source of waves) is that the observer towards whom the bug is moving observes a frequency that is higher than 2 disturbances/second; and the observer away from whom the bug is moving observes a frequency that is less than 2 disturbances/second. This effect is known as the Doppler effect.

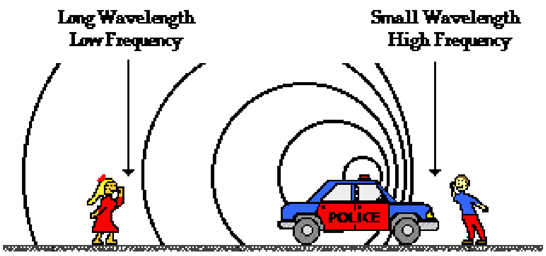


A bug moving to the right and producing disturbances.

The Doppler effect is observed whenever the source of waves is moving with respect to an observer. The **Doppler effect** can be described as the effect produced by a moving source of waves in which there is an apparent upward shift in frequency for observers towards whom the source is approaching and an apparent downward shift in frequency for observers from whom the source is receding. It is important to note that the effect does not result because of an actual change in the frequency of the source. Using the example above, the bug is still producing disturbances at a rate of 2 disturbances per second; it just appears to the observer whom the bug is approaching that the disturbances are being produced at a frequency greater than 2 disturbances/second. The effect is only observed because the distance between observer B and the bug is decreasing and the distance between observer A and the bug is increasing.

The Doppler effect can be observed for any type of wave - water wave, sound wave, light wave, etc. We are most familiar with the Doppler effect because of our experiences with sound waves. Perhaps you recall an instance in which a police car or emergency vehicle was traveling towards you on the highway. As the car approached with its siren blasting, the pitch of the siren sound (a measure of the siren's frequency) was high; and then suddenly after the car passed by, the pitch of the siren sound was low. That was the Doppler effect - an apparent shift in frequency for a sound wave produced by a moving source.

The Doppler Effect for a Moving Sound Source



The Doppler effect is of intense interest to astronomers who use the information about the shift in frequency of electromagnetic waves produced by moving stars in our galaxy and beyond in order to derive information about those stars and galaxies. The belief that the universe is expanding is based in part upon observations of electromagnetic waves emitted by stars in distant galaxies. Furthermore, specific information about stars within galaxies can be determined by application of the Doppler effect. Galaxies are clusters of stars that typically rotate about some center of mass point. Electromagnetic radiation emitted by such stars in a distant galaxy would appear to be shifted downward in frequency (a *red shift*) if the star is rotating in its cluster in a direction that is away from the Earth. On the other hand, there is an upward shift in frequency (a *blue shift*) of such observed radiation if the star is rotating in a direction that is towards the Earth.

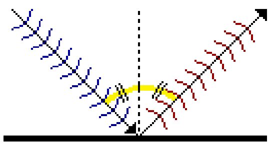
http://www.physicsclassroom.com/class/waves/u10l3d.cfm

EVIDENCE 2: WAVES REFLECT, REFRACT, AND DIFFRACT

A wave doesn't just *stop* when it reaches the end of the medium. Rather, a wave will undergo certain behaviors when it encounters the end of the medium. Specifically, there will be some reflection off the boundary and some transmission into the new medium. The transmitted wave undergoes refraction (or bending) if it approaches the boundary at an angle. If the boundary is merely an obstacle implanted within the medium, and if the dimensions of the obstacle are smaller than the wavelength of the wave, then there will be very noticeable diffraction of the wave around the object. Each one of these behaviors - reflection, refraction and diffraction - is characterized by specific conceptual principles and mathematical equations. Now we will see how light demonstrates this by reflection, refraction and diffraction.

Reflection of Light

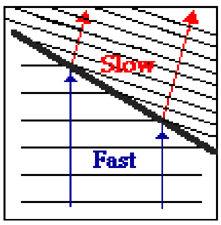
All waves are known to undergo **reflection** or the bouncing off of an obstacle. Most people are very accustomed to the fact that light also undergoes reflection. The reflection of light off of a mirrored surface results in the formation of an image. One characteristic of wave reflection is that the angle at which the wave approaches a flat reflecting surface is equal to the angle at which the wave leaves the surface. This characteristic is observed for water waves and sound waves. It is also observed for light. Light follows the law of reflection when bouncing off surfaces.



Light waves follow the "law of wave reflection."

Refraction of Light

All waves are known to undergo **refraction** when they pass from one medium to another medium. That is, when a wavefront crosses the boundary between two media, the direction that the wavefront is moving undergoes a sudden change; the path is "bent." This behavior of wave refraction can be described by both conceptual and mathematical principles. First, the direction of "bending" is dependent upon the relative speed of the two media. A wave will bend one way when it passes from a medium in which it travels slowly into a medium in which it travels fast; and if moving from a *fast medium* to a *slow medium*, the wavefront will bend in the opposite direction. Second, the amount of bending is dependent upon the actual speeds of the two media on each side of the boundary. The amount of bending is a measurable behavior that follows distinct mathematical equations. These equations are based upon the speeds of the wave in the two media and the angles at which the wave approaches and departs from the boundary. Light is known to refract as it passes from one medium into another medium. In fact, a study of the refraction of light reveals that its refractive behavior follows the same conceptual and mathematical rules that govern the refractive behavior of water waves and sound waves.



The refractive behavior of light reveals that light is very wave-like.

Diffraction of Light Waves

Reflection involves a change in direction of waves when they bounce off a barrier. Refraction of waves involves a change in the direction of waves as they pass from one medium to another. And **diffraction** involves a change in direction of waves as they pass through an opening or around an obstacle in their path. Water waves have the ability to travel around corners, around obstacles and through openings. Sound waves do the same. But what about light? Does light bend around obstacles and through openings? If it does, then it would provide still more evidence to support the belief that light behaves as a wave.

http://www.physicsclassroom.com/class/light/u12l1a.cfm

EVIDENCE 3: WAVES TRAVEL THROUGH A MEDIUM

A wave can be described as a disturbance that travels through a medium from one location to another location. Consider a slinky wave as an example of a wave. When the slinky is stretched from end to end and is held at rest, it assumes a natural position known as the **equilibrium or rest position**. The coils of the slinky naturally assume this position, spaced equally far apart. To introduce a wave into the slinky, the first particle is displaced or moved from its equilibrium or rest position. The particle might be moved upwards or downwards, forwards or backwards; but once moved, it is returned to its original equilibrium or rest position. The act of moving the first coil of the slinky in a given direction and then returning it to its equilibrium position creates a **disturbance** in the slinky. We can then observe this disturbance moving through the slinky from one end to the other. If the first coil of the slinky is given a single back-and-forth vibration, then we call the observed motion of the disturbance through the slinky a *slinky pulse*. A **pulse** is a single disturbance moving through a medium from one location to another location. However, if the first coil of the slinky is continuously and periodically vibrated in a back-and-forth manner, we would observe a repeating disturbance moving within the slinky that endures over some prolonged period of time. The repeating and periodic disturbance that moves through a medium from one location to another is referred to as a **wave**.

When a slinky is stretched, the individual coils assume an equilibrium or rest position.

When the first coil of the slinky is repeatedly vibrated back and forth, a disturbance is created which travels through the slinky from one end to the other.

What is a Medium?

But what is meant by the word *medium*? A **medium** is a substance or material that carries the wave. You have perhaps heard of the phrase *news media*. The news media refers to the various institutions (newspaper offices, television stations, radio stations, etc.) within our society that carry the news from one location to another. The news *moves through* the media. The media doesn't make the news and the media isn't the same as the news. The news media is merely the *thing* that carries the news from its source to various locations. In a similar manner, a wave medium is the substance that carries a wave (or disturbance) from one location to another. The wave medium is not the wave and it doesn't make the wave; it merely carries or transports the wave from its source to other locations. In the case of our slinky wave, the medium through that the wave travels is the slinky coils. In the case of a water wave in the ocean, the medium through which the wave travels is the ocean water. In the case of a sound wave moving from the church choir to the pews, the medium through which the sound wave travels is the air in the room. And in the case of the stadium wave, the medium through which the stadium wave travels is the fans that are in the stadium.

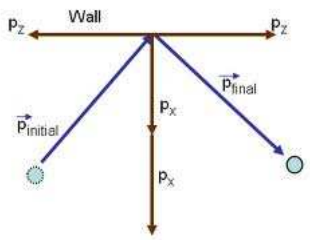
Space and time are not tangible 'things' in the same way that water and air are. It is incorrect to think of them as a 'medium' at all.

http://www.physicsclassroom.com/Class/waves/U10l1b.cfm

http://einstein.stanford.edu/content/relativity/q909.html

EVIDENCE 4: PARTICLES EXHIBIT BOTH SPECULAR AND DIFFUSE REFLECTION

Light emitted by a source, whether near or far, arrives at the mirror surface as a stream of particles, which bounce away or are reflected from the smooth surface, similar to a ball hitting a wall (see image right). Because the particles are very tiny, a huge number are involved in a propagating light beam, where they travel side by side very close together. Upon impacting the mirror, the particles bounce from different points, so their order in the light beam is reversed upon reflection to produce a reversed image.



The particle theory also suggests that if the surface is very rough, the particles bounce away at a variety of angles, scattering the light. This theory fits very closely to experimental observation.

Specular and Diffuse Reflection

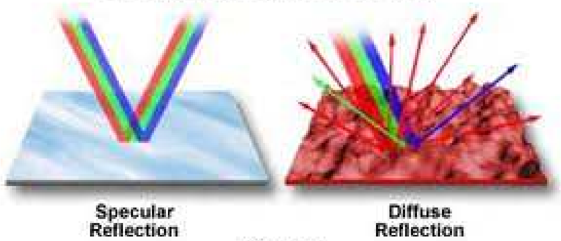


Figure 2

http://www.olympusmicro.com/primer/lightandcolor/particleorwave.html

http://www.mysciencesite.com/optics3.html