

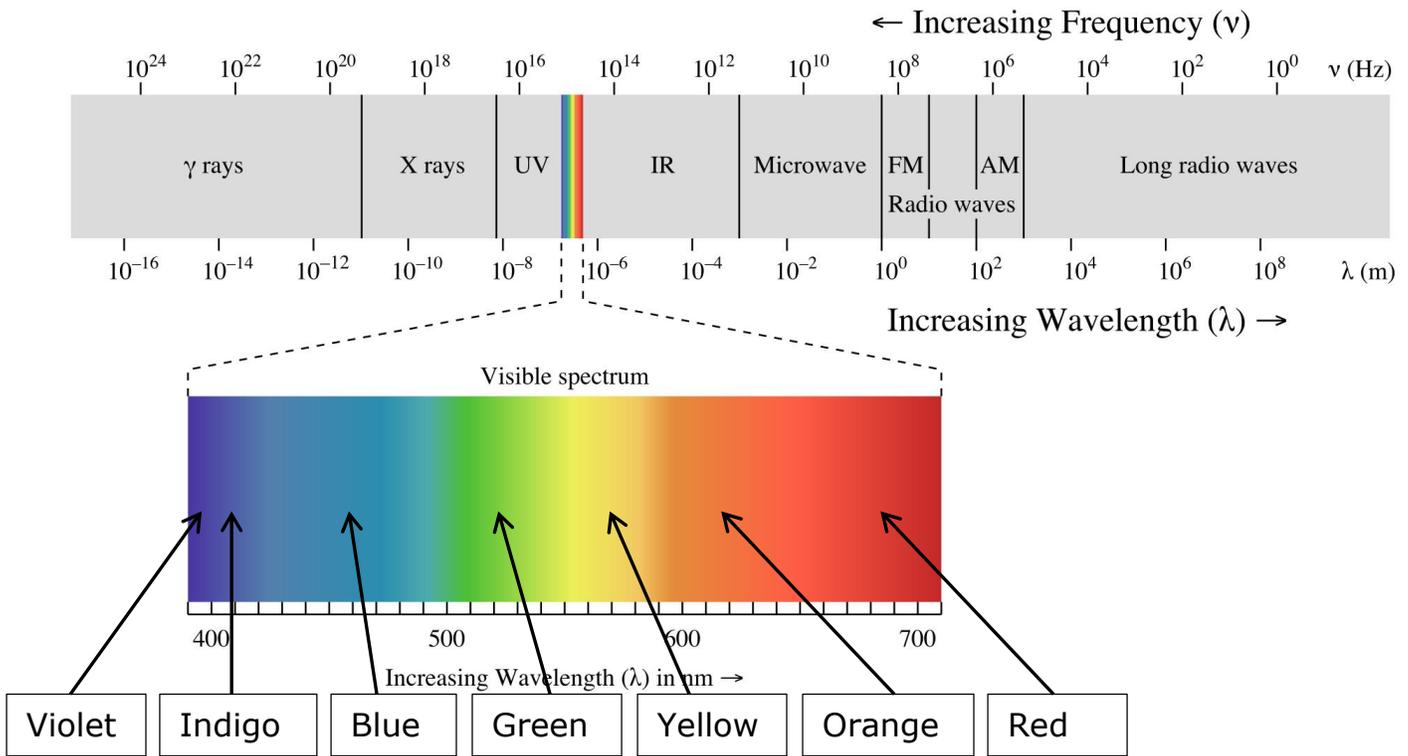
STAAR Science Tutorial 36 **TEK 8.8C: Electromagnetic Waves**

TEK 8.8C: Explore how different wavelengths of the electromagnetic spectrum such as light and radio waves are used to gain information about distances and properties of components in the universe.

The Electromagnetic Spectrum

- Electromagnetic energy is a form of energy that can move through both matter such as air or water, as well as the vacuum of space. The model that scientists use to best describe electromagnetic energy is a transverse wave (shaped much like a non-breaking ocean wave), though it also behaves somewhat like a particle, because it comes in packets of energy of a particular size.
- Each form of electromagnetic energy has a particular range of wavelengths and frequencies. **Wavelength** is the distance between one wave crest and the next. **Frequency** is a measurement of how many waves pass a point in one second. The shorter the wavelength of the electromagnetic energy, the greater the frequency, and the greater the energy contained in the wave.
- The forms of electromagnetic energy that we are most familiar with are light and radio waves. We use our eyes to see and interpret light, the only part of electromagnetic energy we can sense directly. Humans have developed many instruments to create, use and detect the other forms of electromagnetic energy. We use radio waves to transmit television and telephone signals. We use microwaves to cook food and detect storms (radar). We use x-rays to see inside our bodies.
- All electromagnetic energy travels at a constant speed when moving through a particular "medium"—a kind of matter. The so-called "speed of light" is the speed of any electromagnetic wave in a vacuum, without interference with matter. That speed is very fast, about 300,000 kilometers per second. This constant speed allows scientists to use light to measure distance. See *Tutorial 31: Light-Years*. As the medium becomes denser, the speed becomes slower. Some mediums block parts of the electromagnetic energy spectrum completely, while others do not. For example, light cannot pass through the cover of a book, but radio waves and x-rays can.
- Humans rely on our ability to see light to interpret and understand our Universe. Using technology, scientists have extended their ability to see the Universe, by turning the other forms of electromagnetic energy, called the electromagnetic spectrum, into either light or sound.
- The diagram below shows the entire electromagnetic spectrum, with the visible light portion near the center of the spectrum magnified below. (For those reading this on a black-and-white copy, the color names are labeled.) The waves at the left side of this diagram have the most energy and shortest wavelengths, while the

waves at the right side have the longest wavelengths and least energy. The main categories of electromagnetic waves, from left to right, are gamma rays, x-rays, ultraviolet rays, visible light, infrared waves, microwaves and radio waves.



Optical Telescopes

- While many stars and other objects in the sky are visible to the “naked” eye, scientists use telescopes to magnify the visible-light image of objects in the sky, and to increase the apparent brightness of the objects by gathering more light with a large lens or mirror.
- The first telescopes used a pair of glass lenses, a large objective lens at the sky-pointing end, and a smaller eyepiece lens at the viewing-end. The larger the objective lens, the more light is gathered and the greater the number of dimly-lit objects that can be seen.
- Modern telescopes use a large concave mirror to gather light, and usually have a lens connected to an electronic sensor like in a digital camera to see and capture images. The very largest observatories actually use multiple telescopes to look at the same object, and combine the images with computers to get even more detail.
- Telescopes on Earth are usually located on the tops of mountains away from city lights and pollution. Even then, air movement and clouds limit how much can be seen from Earth. The very best telescope images are taken from space, with telescopes such as the Hubble Space Telescope.
- The Hubble Space Telescope has been able to photograph galaxies over 13 billion light-years away from Earth. All of our current estimates of the age of the Universe, and the number of galaxies in the Universe, are based on images and measurements from the Hubble Space Telescope.

- Scientists have launched other space telescopes using infrared waves, ultraviolet waves and even X-rays instead of visible light, to better study objects in space.

Spectroscopes and Light Measurement

- A spectroscope is an instrument that splits white light, which is really a blend of all the separate colors of light, into its individual wavelengths so that they can be each be measured. The overall color of light emitted by stars is directly related to the surface temperature of the star. For this reason, scientists use spectroscopes to determine the surface temperature and color of stars.
- Because each element emits specific bands of colored light unique to that element when it absorbs electromagnetic energy—a color “fingerprint” of the element—scientists can determine what elements are contained in a star.
- The total amount of light emitted by a star, as seen from Earth, is called the star’s **apparent magnitude** or apparent brightness. Scientists use this apparent brightness, along with its distance from Earth, to calculate the star’s **absolute brightness or luminosity**. The size of a star, and thus its mass, can be calculated from its luminosity.

Star Distance Measurements

- When scientists view the pattern of stars in the sky over time, some appear to shift positions slightly as the Earth moves around the Sun. These stars shift because they are closer to Earth—this **parallax** effect can be used to determine the distance to our nearest stars.
- There are a variety of methods that scientists can use to estimate the distance to more-distant stars. For example, some variable stars (stars that vary in brightness over a period of time) are known to have a constant absolute magnitude. By measuring their apparent magnitude (the brightness as seen from Earth), the star’s distance from Earth can be calculated.

Doppler Shift

- When electromagnetic waves are emitted from a very fast moving object, the distantly-viewed waves are either compressed or stretched out, depending on whether the object is moving towards the viewer or away from the viewer. If the object is moving towards the viewer, they are compressed into shorter wavelengths. If the object is moving away from the viewer, the waves are stretched out, making the wavelengths longer. In visible light, the light appears to shift towards the blue side of the spectrum (“blue-shift) if moving towards the viewer, and towards the red side of the spectrum (red-shift) if moving away from the viewer. This is called the Doppler Shift or Doppler Effect.
- Scientists use Doppler shift to determine whether distant stars and galaxies are moving towards us or away from us. In the late 1920s, astronomers Georges Lemaitre and Edwin Hubble separately proposed that all distant galaxies are moving away from Earth (red-shifted), and that the further away a galaxy was, the faster it was moving. From this discovery, scientists began to accept that the Universe is expanding. Scientists now believe that the Universe began to expand

from a single point in space some 13.7 billion years ago—the “Big Bang Theory.” See *Tutorial 34: Stars, Galaxies, Universe* for a more detailed discussion of this theory.

- Unlike the distant galaxies observed by Hubble, galaxies in our local group are moving towards us (blue-shifted). Scientists believe that all of the galaxies in our Local Group will eventually merge together.
- The revolution rate of the Milky Way Galaxy around its center has been measured by Doppler Shift methods. It takes about 200 million years for the stars in the Milky Way Galaxy to revolve once around the galaxy’s central black hole.

Radio Telescopes

- Scientists can also use telescopes to “see” images of radio waves and microwaves, by using arrays of widely spaced dish antennas (similar to those used by Dish TV, but much bigger) to receive the signals. A computer is used to translate the varying signal strength into false colors representing the signal strength, and thus “see” an image of the radio waves.
- Radio and microwave images have the advantage of being able to see through clouds of dust that block visible light, and see objects that are too cool to emit the other kinds of electromagnetic waves. The biggest disadvantage of radio telescopes is that the long wavelength of the radio waves cannot capture as much detail as shorter wavelength visible light. This is why scientists today use multiple widely spaced antennas—to increase detail.
- Using radio-telescopes, scientists have been able to get a whole-sky microwave image of space, and capture the background radiation left over from the “big-bang” creation of the Universe.

Practice Questions

1. Electromagnetic energy has properties of both _____ and _____.
2. The _____ of a wave is the distance from one wave crest to the next, while its _____ is the number of waves that passes a point in one second.
3. The longer the wavelength of an electromagnetic wave, the more _____ that it contains.
4. The speed of all electromagnetic waves in space is _____ kilometers per second.
5. The seven different parts of the electromagnetic spectrum, stated from the shortest wavelength to the longest, are (1) _____; (2) _____; (3) _____

_____ ; (4) _____ ;
(5) _____ ; (6) _____ ;
and (7) _____ .

6. Scientists use _____ to measure the color of light.
7. The _____ of the surface of a star can be determined from a star's color.
8. Bands of light in a star's spectrum allow scientists to determine what _____ are in the star.
9. The brightness of a star as seen from Earth is its _____. The actual brightness of a star, calculated by knowing its distance from Earth and apparent brightness, is its _____ or _____.
10. The distance to stars that are close to Earth can be measured by _____.
11. The _____ allows scientists to determine whether a star is moving towards or away from Earth. If the light from the star is _____-shifted, it is moving away from Earth. If the light is _____-shifted, it is moving towards Earth.
12. One of the main pieces of evidence supporting the Big Bang Theory is the fact that all distant galaxies are _____-shifted, meaning that they are moving _____ from Earth.
13. Another piece of evidence supporting the Big Bang Theory is the _____ background of space, which was measured with radio telescopes.