**Week 8**

**Physics 1409/1430 – Physics 2**

Hello and Welcome to the weekly resources for PHY 1409/1430 – Physics 2!

This week is Week 8 of classes, and typically in this week of the semester, your professors are covering these topics below. If you do not see the topics your particular section of class is learning this week, please take a look at other weekly resources listed on our website for additional topics throughout the semester.

We also invite you to take a look at the group tutoring chart on our website to see if this course has a group tutoring session offered this semester.

If you have any questions about these study guides, group tutoring sessions, private 30-minute tutoring appointments, the Baylor Tutoring YouTube channel or any tutoring services we offer, please visit our website www.baylor.edu/tutoring or call our drop in center during open business hours, M-Th 9am-8pm on class days, at 254-710-4135.

**Keywords:** EM Waves, EM Spectrum, Energy and Momentum in EM waves

Important Information

Cool Physics Things!

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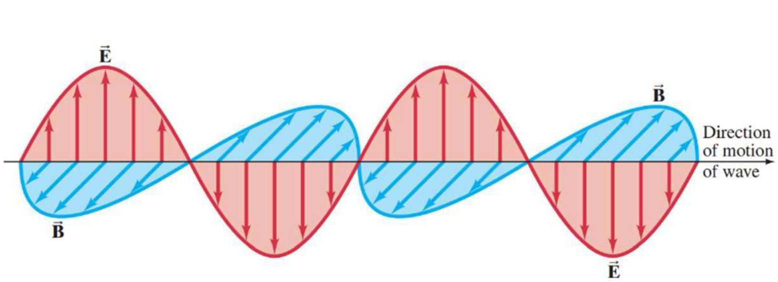
**<u>Electromagnetic Waves:</u>**

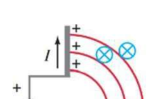
Thus far, we have learned about the relationship between the electric field and the magnetic field. The change in one of them causes a change in the other. The way they interact with one another is fascinating. But what is most interesting is what their interaction produces. The interaction of the electric field and the magnetic field makes up what we see as light. Light is an electromagnetic wave.




What does this mean physically? It is best represented by the figure above. The electric field and the magnetic field work simultaneously to produce an electromagnetic wave. The fields are always perpendicular to one another.

These electromagnetic waves are produced by oscillating electric charges. So, to make it simpler to imagine, think of the electric charges as super bouncy balls, and you bounced one off

All images are from Physics: Principles with Applications (7th Edition) by Douglas C. Giancoli



the ground, and it keeps on bouncing. As it bounces, imagine horizontal field produced every time it bounces. This is what is happening continuously and it's producing the electromagnetic wave we see above.

We also use the same principle to produce EM waves for our uses. We use antennas to do so. When current is passing through these antennas, it produces an electric field. Weuse ac electricity to continuously change the direction of the current, hence changing the electric field direction. When we produced and electric field, we produced a magnetic field, which will also oscillate, this creates the EM waves (shown in the figure on the right).

Using these principles, Maxwell derived the fundamental equations we use in the field of electromagnetism and eventually applied them to EM waves. Using that, he was mathematically able to determine the speed of light before we could even measure it!

$$c = \frac{1}{\sqrt{\epsilon_0 \mu_0}} = \frac{1}{\sqrt{(8.85 \times 10^{-12}\,\mathrm{C^2/N \cdot m^2})(4\pi \times 10^{-7}\,\mathrm{N \cdot s^2/C^2})}} = 3.00 \times 10^8\,\mathrm{m/s.}$$

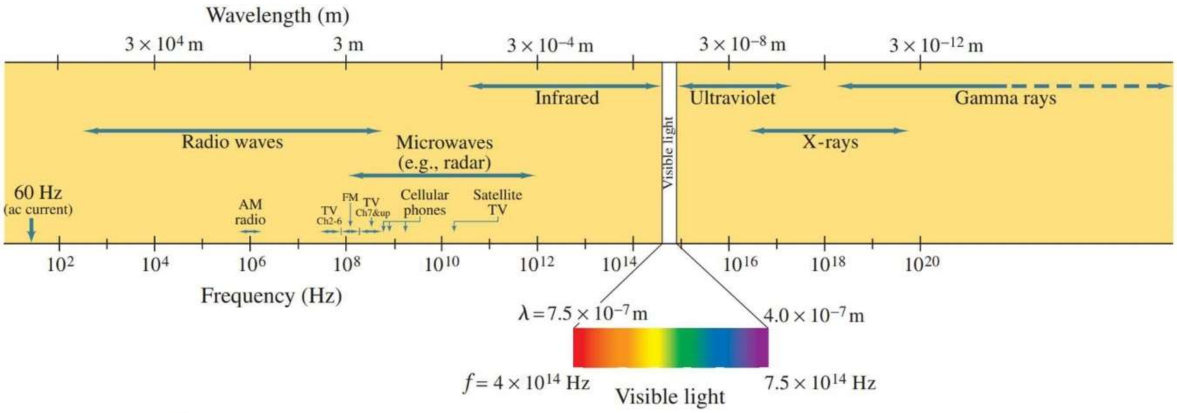
But beyond just the numerical significance of this derivation, it also means that all electromagnetic wavestravel at the SAME speed in a vacuum. So, all the different types of EM waves all have the same speed. But then how are they so different in behavior from one another? That's because they only vary in the frequency and wavelength of the wave. So,

$$c = \lambda f$$

where $\lambda$ is the wavelength of the wave and f is the frequency of the EM wave.

## Electromagnetic Spectrum

Light (visible light in physics terms) is only one type of EM waves. Due to the relationship above, we refer to the different types of EM waves in terms of the spectrum created by the frequencies and wavelengths of the waves.




We identify these different kinds of light by finding either their wavelength or frequency. There are so many different places we use them.

As you move right on the spectrum, the frequency of the waves increase, and the wavelengthdecreases. Hence, the waves on the right are much smaller. Remember this relationship.

**Energy and Momentum in EM Waves**

Much like all waves, EM waves carry energy. EM waves do not require a medium for propagation unlike other waves like sound. In sound, the energy with transported using the air molecules but EM waves are a product of the electric and magnetic field, so the electric and magnetic field carry the energy for EM waves.

Since EM waves consist of the electric field and the magnetic field, we can use them to find the energy that EM waves are transporting. There are three equations you can use. Choose them appropriately by determining what the question provides you with.

$$u = \epsilon_0 E^2 \qquad u = \frac{B^2}{\mu_0} \qquad u = \sqrt{\frac{\epsilon_0}{\mu_0}}\, EB$$

This u stands for the energy per unit volume. So, it is actually the energy density. So, for energy in a given space, just multiply by the volume of the space.

Since it is a wave, it is also important to know its intensity (energy transported per unit area per unit time).

$$I = \epsilon_0 c E^2 \qquad I = \frac{EB}{\mu_0}$$

Since EM waves are sinusoidal, we can calculate the average intensity, electric field and magnetic field similar to how we do with voltage and current in AC electricity. EM

$$\overline{I} = \frac{1}{2}\epsilon_0 c E_0^2 = \frac{1}{2}\frac{c}{\mu_0}B_0^2 = \frac{E_0 B_0}{2\mu_0}$$

waves also carry momentum, which may seem weird because of our conventional sense where we saw things with mass carry momentum. But since, EM waves carry energy, they also carry momentum because they can impart that energy to things they collide with. The momentum it imparts is dependent upon whether the object it strikes absorbs all of its energy or reflects all ofits energy.

If fully absorbed, the change in momentum is

$$\Delta p = \frac{\Delta U}{c}$$

If fully reflected, the change in momentum is

$$\Delta p = \frac{2\,\Delta U}{c}$$

Now, since there is a change in momentum, it means that there was an impulse between the wave and the surface. A force was exerted on the surface. This force per unit area of the surface is called the radiation pressure. Interestingly, this is how we feel heat from sunlight. This force imparted when we absorb the photons, this radiation pressure, is what we feel as heat!

If full absorbed, the radiation pressure is

$$P = \frac{\overline{I}}{c}$$

If fully reflected, the radiation pressure is

$$P = \frac{2\overline{I}}{c}$$

In reality, our perspective, light is different, we see them as rays, not waves. We see light as rays of photons. How can it be a wave? Light travels as a wave and a particle, which is called the wave particle duality of light. How it is true is a more complicated discussion and beyond the confines of this course, but it is truly fascinating and something worth looking into on your own.

## CHECK YOUR LEARNING

1. Which of the following travel at the same speed as the speed as light?
   a. Radio waves
   b. Gamma Rays
   c. Microwaves
   d. Infrared Radiation
   e. X-ray
   f. Light from your TV screen
   g. All of the above

2. Which quantity is smaller for microwaves compared to ultraviolet radiation?
   a. Intensity
   b. Amplitude
   c. Frequency
   d. Wavelength

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## THINGS YOU MAY STRUGGLE WITH

1. The speed of electromagnetic waves is the SAME for all forms of electromagnetic waves. They all travel at the speed of light. The thing that varies is the frequency and wavelength of the electromagnetic waves.
2. As you go up the spectrum, frequency INCREASES and wavelength DECREASES.
3. The electromagnetic waves are difficult to visualize. Remember that they are composed of the electric field and magnetic field being produced and reduced simultaneously. So as the electric field is produced, the magnetic field is produced. These oscillate as they travel.
4. Understanding how EM waves can exist in a vacuum where there is no medium for it to travel through. Remember, they still carry energy, which is what a wave is composed of. For sound, the waves conduct energy through the molecules in the medium but for light, that energy is contained in the electric and magnetic field.
5. As EM waves have energy, this energy can be transferred to objects they collide with. Light, even though it is massless has momentum because it has energy. So, when they collide with something, they exert radiation pressure, which is proportional to the intensity of the wave.

**Thanks for checking out these weekly resources! Don't forget to check out our website for group tutoring times, video tutorials and lots of other resource: www.baylor.edu/tutoring ! Answers to check you learning questions are below!**

Answers: 1. (g) 2. (c)

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