Lab 11: Electromagnetic Waves

Elias Faughn, Alec Gray, Jonah Spector

Introduction

While light is often associated with visibility, only a small portion of the electromagnetic spectrum is actually visible to the human eye. Despite this, we've managed to reveal the impact this light has on the world around it, and through that we are able to interact with and understand these invisible frequencies. In this lab we intend to investigate the ways in which low to medium frequency radio waves can be interrupted and disturbed by surrounding objects, alongside investigating how Infrared radiation interacts with different surfaces, alongside finding objects that only emit in the IR spectrum.

Defining Terms

An object absorbs light when electromagnetic waves don't reflect off the surface. This makes them appear darker in whatever frequency is being absorbed, as the waves that are absorbed aren't reflected back into the observer's eyes/camera. For example, chlorophyll pigment in plants reflects green visual light, which is why plants are green.

Physically, this is caused by the chemical properties of the matter oscillating differently with incoming plane waves. The electromagnetic waves interact with the charged, low-mass electrons causing them to oscillate. If the oscillation interferes with the plane wave, light is reflected (e.g. wood, to some degree); and, if the oscillation is in line with the plane wave, the light is transmitted (e.g. water, to some degree). All types of oscillation exist in between and give rise to many optical properties of matter.

Objects can also emit light from non-induced oscillations. For example, an alternating current can cause electrons to oscillate and produce electromagnetic waves. Heat, which is the general random movement or vibration of atoms, can also cause electrons to oscillate and produce electromagnetic waves (e.g. IR radiation produced by humans). If there is no outside light to be reflected by an object, and it still seems to reflect light, it could be *emitting* the light itself.

Derivation of Electromagnetic Waves

For fun, and to have a bit of math in this lab, here is a derivation of the wave equation for light from Maxwell's equations. The three equations needed are:

$$\vec{\nabla} \times \vec{E} = -\frac{\partial \vec{B}}{\partial t} \qquad \vec{\nabla} \cdot \vec{E} = \frac{\rho}{\epsilon_0} \qquad \vec{\nabla} \times \vec{B} = \mu_0 \left(\vec{J} + \epsilon_0 \frac{\partial \vec{E}}{\partial t} \right)$$

Next, take the curl of Faraday's Law and apply identities:

$$\vec{\nabla} \times \left(\vec{\nabla} \times \vec{E} \right) = \vec{\nabla} \times \left(-\frac{\partial \vec{B}}{\partial t} \right)$$

$$\vec{\nabla} \left(\vec{\nabla} \cdot \vec{E} \right) - \vec{\nabla}^2 \vec{E} = -\frac{\partial}{\partial t} \left(\vec{\nabla} \times \vec{B} \right)$$

Assuming there are no charges or currents ($\rho = 0$, $\vec{J} = 0$) and plugging in the previous equations:

$$\vec{\nabla}^2 \vec{E} = \frac{\partial}{\partial t} \left(\mu_0 \epsilon_0 \frac{\partial \vec{E}}{\partial t} \right)$$

$$\boxed{\vec{\nabla}^2 \vec{E} = \mu_0 \epsilon_0 \frac{\partial^2 \vec{E}}{\partial t^2}}$$

The wave equation is defined as:

$$\vec{\nabla}^2 \vec{U} c^2 = \frac{\partial^2 \vec{U}}{\partial t^2}$$

The propagation speed of the wave is c^2, therefore the speed of electromagnetic waves (light) is:

$$\vec{\nabla}^2 \vec{E} = \mu_0 \epsilon_0 \frac{\partial^2 \vec{E}}{\partial t^2}$$

$$\vec{\nabla}^2 \vec{E} \frac{1}{\mu_0 \epsilon_0} = \frac{\partial^2 \vec{E}}{\partial t^2}$$

$$c^2 = \frac{1}{\mu_0 \epsilon_0}$$

$$\boxed{c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}}$$

Radio Locations

Materials: Radio (Listening on AM Frequency)

Methods: Tune the radio, once a signal is acquired, hold the radio close to your body. Rotate around, take note of how much of an impact the static has on the overall audio output of the radio.

Results: While rotating around, we'd notice that the signal was the strongest while facing South, and weakest while facing to the North West.

Analysis: AM radio works by detecting the oscillating magnetic field of radio waves. The solenoid coils are best aligned as seen in the image to maximize the current based on the specific magnetic flux through the enclosed area.

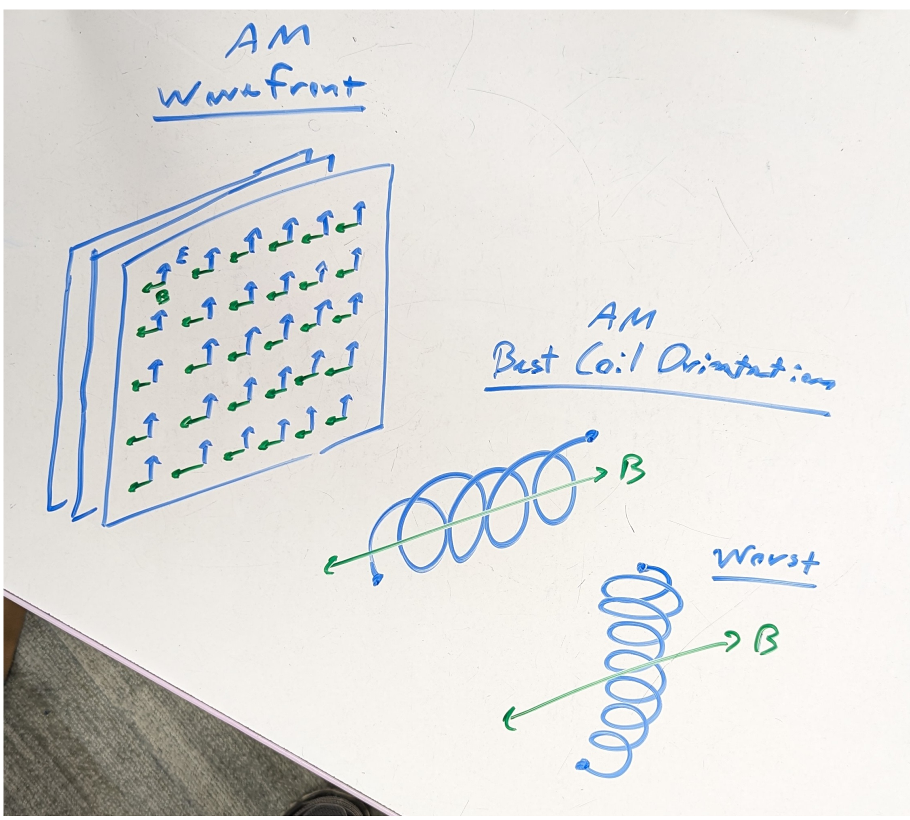

Figure 1: AM Radio Coils

Near Infrared Goggles

Materials: Near IR Filter Goggles

Methods: Put the goggles on and wander around campus. Take notes of objects demonstrating behavior of note.

Results: We noticed that trees and other plants reflect near IR light, windows and the air itself all transmit light, almost any dark colored object, such as the keys on my keyboard absorb IR light. Anything that emits heat should also come with infrared radiation, such as a computer running hot, or even people.

Analysis: We noticed that darker color objects tend to absorb IR light, with lighter colors reflecting it. It should be worth noting that near IR light, when viewed by the human eye, appears red due to the fact that it exists on a frequency extremely close to red, where small deviations could likely cause the normally invisible light to appear as red.

Measuring Temperature with Thermal Radiation

Materials: Infrared camera.

Methods: Use the infrared camera to image a variety of objects and determine how they interact with IR light by how they appear on camera.

Results: The pipes were ambient temperature while the pipe connections were very warm, visible in figure 2. The chimneys on top of the building were very cold while the metal around it seemed to reflect heat, seen in figure 3. The water from the water fountain was very cold. A thermal reflection could be seen in the metal of the water fountain as seen in figure 4. Jonah's hand that got wet was colder than the hand that was not wet as seen in figure 5.

Analysis: The pipes are room temperature because they insulate the exterior from whatever is on the interior. The connectors are very hot because the insulation of the pipe is not as good there so the heat in the pipe is being emitted. The chimneys from Glover seem to be absorbing heat because they are cold. The metal is reflecting heat, this is why it is hot but not emitting. The water absorbed heat very well which is why it appears so dark, since IR is light, it was reflected by the metal on the fountain which is why a reflection appears. The water also soaked the heat from Jonah's hand which is why one hand was darker than the other.

Conclusion

Electromagnetic waves, which act as photons, are the fundamental force-carrier of the electromagnetism. Most chemical reactions, optics, and physical interactions with the universe would not be possible without them. For example, as we saw in this lab, electromagnetic radiation is a powerful carrier of heat energy.

The temperature of objects we saw around campus was very closely related to their exposure to the sun's radiation. It was also clearly a measure of the temperature of objects, as best demonstrated by the water fountain. Overall, the applications of electromagnetic waves to science and engineering are priceless, and understanding the underlying principles is likewise very important.

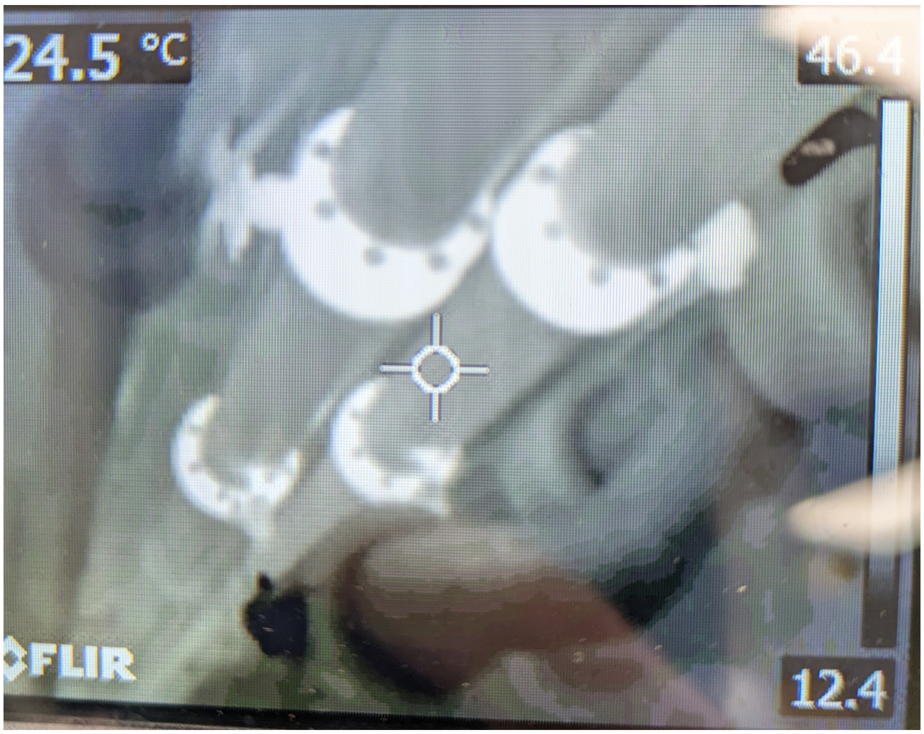

Figure 2: Pipe Connections

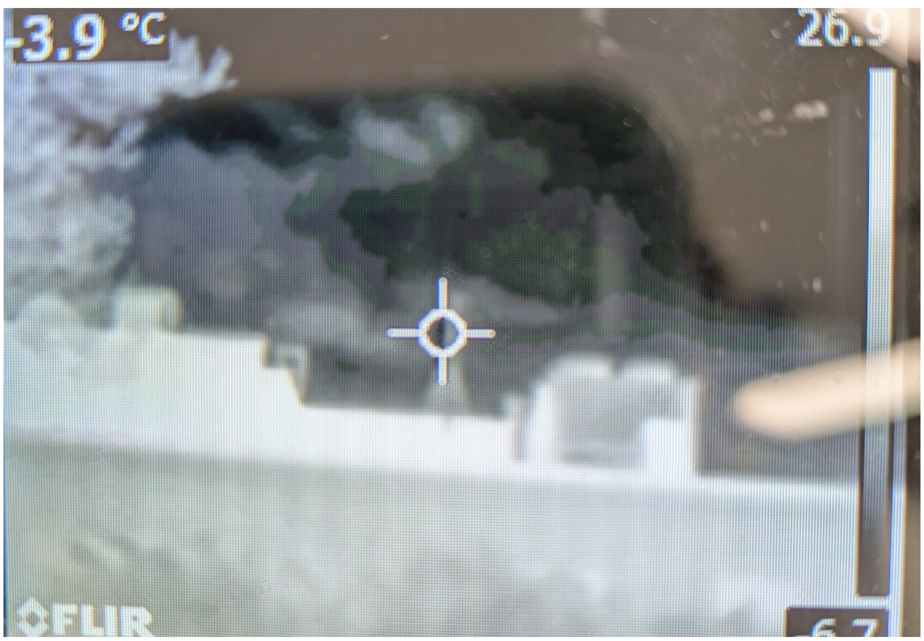

Figure 3: Building AC

Figure 4: Water Fountain

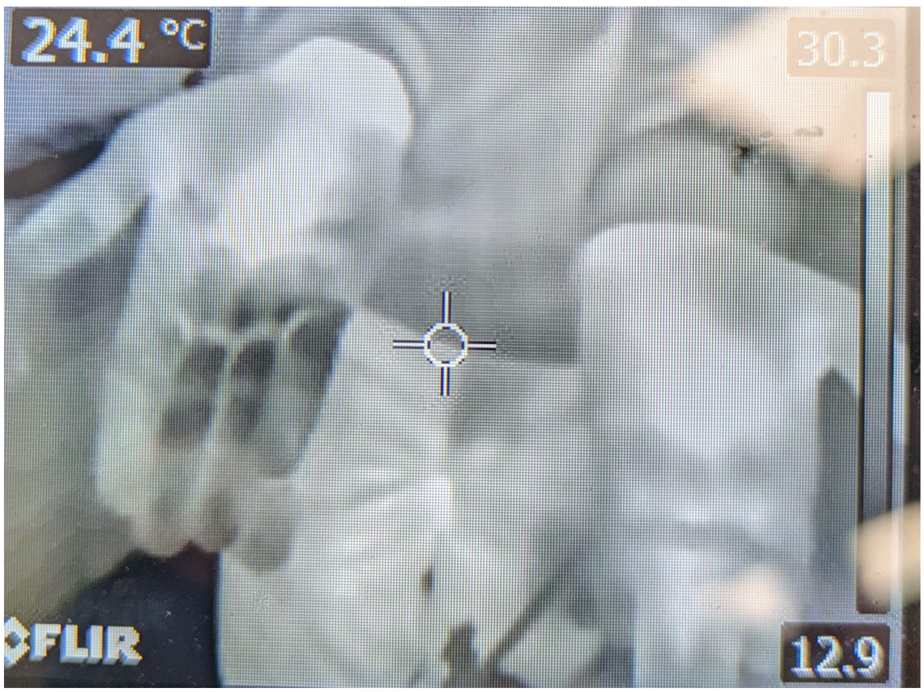

Figure 5: Wet Hand

Figure 6: Elias