

## Slide 1 – Title Slide

Hello and welcome to Week 9, part 2 of EGM310: Electromagnetic Radiation. In this lesson, we'll cover the basics of electromagnetic radiation, the main tool we use to gather information in remote sensing.

## Slide 2 – Recall

In the previous lesson, we discussed how in a way, we've all been doing remote sensing for years. Our eyes, ears, and nose all collect data about the world without touching it – they are remote sensors. In particular, our eyes use light in order to sense the world around us – in a very similar way to how we collect remote sensing data.

## Slide 3 – Light

The light that we see is a type of electromagnetic radiation, and we'll talk more about what we mean by electromagnetic radiation in a minute. For most remote sensing, we use electromagnetic radiation to observe things. But, how should we think about, or picture, light (or electromagnetic radiation)? Please note that in this lesson, I'm going to be using light and electromagnetic radiation interchangeably – we'll learn why that is a bit later.

Over time, physicists developed two main theories for how light behaved – the particle model, and the wave model – based on different phenomena or properties they observed. So, is light a particle, or is it a wave?

The table to the right here lists the different properties, and indicates which of the two models can be used to explain each one. Both models can explain reflection and refraction, but only the wave model can explain the properties of interference, diffraction, and polarization. But, the wave model can't explain the photoelectric effect (see additional resources), whereas the particle model can. So, the answer to the question “is light a particle or a wave?” is “it depends.” The reason why is well outside of the scope of this course, but if you're interested there are more links at the end of the presentation (or in the description below) that go a bit deeper into the topic.

## Slide 4 – The Wave Model

Electromagnetic radiation is a self-propagating wave. By “self-propagating” we mean that, unlike water waves or sound waves, electromagnetic waves travel through space without any external influence. As the name suggests, electromagnetic waves have both an electric component and a magnetic component. One of the major lessons of 19th-century physics is that a changing electric field induces a magnetic field, and vice-versa – this is the principle behind, among other things, induction stovetops and electric motors.

So an electromagnetic wave moving through space has both an electric and a magnetic component, usually denoted  $E$  and  $B$ , respectively. The electric component is moving and oscillating in one plane –

in this example, the xz-plane, while the magnetic component moves and oscillates in a plane at a 90-degree angle – in this example, the xy-plane.

Like any other wave, an electromagnetic wave has different attributes, or properties. It propagates at a certain speed, usually denoted 'c'. In a vacuum, the speed of light is about  $3 \times 10^8 \text{ m s}^{-1}$ . In other materials, such as Earth's atmosphere, it drops by about 90 km/s – about .03% slower. We can also define the wavelength of an electromagnetic wave as the distance between one full cycle – this can be measured between successive peaks as shown here, or between successive 'troughs', or the distance between points where the electric component is 0. Another important property is the frequency, usually denoted f, of the wave – this is the amount of time it takes to go through a single cycle. The wavelength and frequency are both related to the speed of the wave according to this equation here: the speed of the wave is just the wavelength times the frequency.

Other properties of electromagnetic waves include the phase, or the fraction of a cycle. As you might have guessed, this is usually defined between 0 and  $2\pi$ , or 0 and 360 degrees. Finally, there's the amplitude, which is the height of the peak or the depth of the trough, and this is associated with the brightness or intensity of the light. The table here lists the different components, and their respective units.

## Slide 5 – The Wave Model

Light is a transverse wave – that is, the electric and magnetic components of the wave oscillate perpendicular to the direction of motion. We can therefore define, or specify, an orientation for this oscillation, called the polarization of the wave. By convention, we normally define the polarization using the electric component of the wave.

In this top example, the wave is vertically polarized – the electric field is oriented along the x-axis, in the xz-plane. In the second example, the electric field is still propagating along the x-axis, but it is oscillating in the xy-plane – we would say that this is horizontally polarized. Light can be polarized at any arbitrary angle – it can even have a circular or elliptical polarization, where the plane is rotating around the direction of motion. Just as a side note, the fact that electromagnetic waves have a polarization is used frequently in microwave or radar remote sensing.

Because of this, we can actually construct filters that will only allow through light at a specified polarization. This is especially useful for radar remote sensing, where the polarization of the radar signal partly determines what we actually "see" with the signal. We can also use this to create glare-reducing polarized sunglasses, for example.

## Slide 6 – The particle model

Remember that I said light can behave as both a particle and a wave. We've seen how we can describe light as a wave, and now we'll take a look at the particle model. In this model, light is a particle, called a photon, that has a particular energy Q. Another of the big discoveries of 19<sup>th</sup> and early 20<sup>th</sup> century physics is that objects (that is, atoms), can only absorb and emit energy in discrete units, called quanta, or photons. And if you're wondering, yes – this is where we get the term "quantum mechanics."

The amount of energy, then, that a photon has is directly related to its frequency by a constant known as Planck's constant. Using what we know about the relationship between the frequency and wavelength of light, we can re-write this using the equation on the bottom of the slide here, with the table showing the units of the different variables on this slide.

## Slide 7 – Implications

So, the energy contained in a photon is inversely proportional to its wavelength. Or, put another way, longer wavelengths mean lower frequencies mean lower energy. And, conversely, shorter wavelengths mean higher frequencies mean higher energy. For remote sensing, this also means that longer wavelengths are harder to detect – we need more photons at lower energies to strike our sensor in order to register a signal, compared to higher-energy photons.

## Slide 8 – Blackbody radiation

All matter that has a temperature above 0 Kelvin (-273.15 degrees Celsius) emits electromagnetic radiation. The amount of radiation that is emitted, also called the radiant emittance, strongly depends on the temperature.

For an idealized object, called a blackbody, that perfectly absorbs and re-emits all of the energy that falls on it, the radiant emittance is directly proportional to its temperature raised to the fourth power – this first equation here is known as the Stefan-Boltzmann law. So, relatively small increases in temperature lead to large increases in radiant emittance. In reality, most objects aren't perfect blackbodies – instead, they emit some fraction of the electromagnetic radiation that blackbodies do. We can measure how well an object approximates a perfect blackbody via its emissivity, which is defined as the ratio of its emittance to that of a blackbody with the same temperature. And again, the table here shows the different units for the variables shown on the slide.

## Slide 9 – Blackbody radiation

So, starting to put all of this together, we see that objects with higher temperature have higher energy; and, the electromagnetic radiation they emit will have a higher frequency, or a shorter wavelength. This also means that the “color” of electromagnetic radiation that an object emits changes as well.

The plot here shows how an object's radiance (amount of energy emitted) varies with both wavelength and temperature. Note that this is a semi-logarithmic plot – the steps on the y-axis represent an increase of 1000, while the steps on the x-axis go from 100, to 1000, to 10000, and so on.

Cooler objects, shown as darker lines on the plot, have lower overall radiance – and the wavelengths they emit most at are much longer. As we increase in temperature, we also increase the overall radiance – the peak gets higher and higher – and we shift the peak of the curve toward lower wavelengths.

In space, our sun appears mostly white because it emits fairly evenly across the wavelengths that we can see with our eyes, though our atmosphere changes this slightly. Wood fires with a temperature of

around 1500 K appear mostly reddish-orange to our eyes, while the human body at  $\sim 300\text{K}$  doesn't really emit at all in the wavelengths our eyes can see.

We can calculate the dominant wavelength that an object emits (i.e., the color of its maximum radiance) using something called Wien's displacement law – I think we've had plenty of equations already in this lesson, so that's one for you to look up later.

## Slide 10 – Electromagnetic spectrum

Electromagnetic radiation comes in a large range of possible wavelengths or frequencies, which we call the electromagnetic spectrum.

We can somewhat arbitrarily divide the spectrum into regions of wavelengths with “similar enough” properties. As you can see here, the light that we can see with our eyes, known as visible light or visible EMR, makes up a very small portion of the electromagnetic spectrum, with wavelengths between about 400 and 700 nanometers. Just below visible light we have ultraviolet light, with wavelengths between about 10 and 400 nanometers. Above the visible spectrum we have infrared light, followed by microwaves and then radio waves, which can have wavelengths over several kilometers in length. Each of these different regions has its own properties that we can use to study different things.

## Slide 11 – Divisions of the EM spectrum

As I mentioned, the divisions are somewhat arbitrary, and different users may have different definitions, or different preferred units. Electrical engineers and people who do microwave remote sensing tend to prefer Herz (frequency units), while people who do optical/thermal remote sensing tend to prefer wavelength units. The table on the left-hand side of the screen lists a number of different portions of the electromagnetic spectrum that we often use for remote sensing – you can look this over and see the different sort-of definitions here. One thing to think about before the next lesson – why haven't I listed any wavelengths shorter than visible light?

## Slide 12 - Summary

As we've seen, electromagnetic radiation, or light, has properties of both a wave and a particle, which is only a small part of what makes our universe such a strange and wonderful place.

The energy of electromagnetic radiation depends on its wavelength or frequency – higher wavelengths/lower frequencies mean less energy, and vice-versa.

All objects with a temperature over absolute zero (0K) emit electromagnetic radiation, the amount of which and color of which depends on the temperature.

Finally, we can think of electromagnetic radiation as existing on a spectrum of wavelengths or frequencies, and divide these up depending on their properties.

## **Slide 13 – Additional resources**

You can read more about the topics we've discussed here in the two textbooks – Lillesand, Kiefer & Chipman, Chapter 1, or Campbell & Wynne, Chapter 2. Or, read more about it from the Natural Resources Canada Remote Sensing Tutorials. I've also included links that cover some of extra topics we didn't get into, like the photoelectric effect and "the ultraviolet catastrophe", which goes into some more details about blackbody radiation and the history of its study. That's all for this lesson – I hope you found it interesting, and you have any questions, please don't hesitate to e-mail me or post in the discussion forum on blackboard. Bye!