Chapter 1

Electromagnetic Waves

Sound is a compression wave — to travel, it needs a medium to compress: air, water, etc. (Regardless of what you have seen in movies, sound does not travel through a vacuum!)

Light is an electromagnetic wave — it causes fluctuations in the electric and magnetic fields that are everywhere. It can cross a vacuum, as it does to reach us from the sun.

Electromagnetic waves travel at about 300 million meters per second in a vacuum. The waves travel slower through different types of matter. For example, an electromagnetic wave travels at 225 million meters per second in water.

Electromagnetic waves come in different frequencies. For example, the light coming out of a red laser pointer is usually about 4.75×10^{14} Hz. The wifi data sent by your computer is carried on an electromagnetic wave too. It is usually close to 2.4×10^6 Hz or 5×10^6 Hz.

Because we know how fast the waves are moving, we sometimes talk about their wavelengths instead of their frequencies. Since we know its speed and its oscillation rate, we can calculate its wavelength. Since we want the distance per oscillation, we can divide the speed by the frequency. The light coming out of a laser pointer is $300 \times 10^6 / 4.75 \times 10^{14} = 630 \times 10^{-9}$ m, or 630 nm.

Exercise 1 Wavelengths

A green laser pointer emits light at 5.66×10^{14} Hz. What is its wavelength in a vacuum?

Working Space

Answer on Page 7

This can be simplified as:

$$\lambda = \frac{c}{f}$$

where $c = 3 \times 10^8$ m/s (the speed of light in a vacuum)

We have given names to different ranges of the electromagnetic spectrum in Figure 1.1

Name	Hertz	Meters
Gamma rays	$10^{20} - 10^{24}$	$10^{-14} - 10^{-11}$
X-rays	$10^{16} - 10^{20}$	$10^{-11} - 10^{-8}$
Ultraviolet	$10^{15} - 10^{16}$	$10^{-8} - 10^{-7}$
Blue	$\sim 6 \times 10^{14}$	$\sim 5 \times 10^{-7}$
Red	$\sim 4 \times 10^{14}$	$\sim 7 \times 10^{-7}$
Infrared	$10^{12} - 10^{14}$	$10^{-6} - 10^{-3}$
Microwaves	$10^{9} - 10^{12}$	$10^{-3} - 10^{-1}$
Radio waves	$10^{3} - 10^{9}$	$10^{-1} - 10^{5}$

Figure 1.1: A table of different ranges of the electromagnetic spectrum.

(You may have heard of "cosmic rays" and wonder why they are not listed in this table. Cosmic rays are actually the nuclei of atoms that have been stripped of their electron cloud. These particles come flying out of the sun at very high speeds. They were originally thought to be electromagnetic waves, and were mistakenly named "rays".)

In general, the lower frequency the wave is, the better it passes through a mass. A radio wave, for example, can pass through the walls of your house, but visible light cannot. The people who designed the microwave oven chose the frequency of 2.45 GHz because the energy from those waves tended to get absorbed in the first few inches of food that it passed through.

1.1 The greenhouse effect

Humans have dug up a bunch of long carbon-based molecules (like oil and coal) and burned them, releasing large amounts of CO_2 into the atmosphere. It may not be obvious why that has made the planet warmer, but the answer is electromagnetic waves.

A warm object gives off infrared electromagnetic waves. That's why, for example, motion detectors in security systems are actually infrared detectors: even in a dark room, your body gives off a lot of infrared radiation.

You may have heard of "heat-seeking missiles." These are more accurately called "Infrared homing missiles" because they follow objects giving off infrared radiation – hot things like jet engines.

The sun beams a lot of energy to our planet in the form of electromagnetic radiation: visible light, infrared, ultraviolet. (How much? At the top of the atmosphere directly facing the sun, we get 1,360 watts of radiation per square meter. That is a lot of power!)

Some of that radiation just reflects back into space. 23% is reflected by the clouds and the atmosphere, while 7% makes it all the way to the surface of the planet and is reflected back into space.

The other 71% is absorbed. 48% is absorbed by the surface and 23% is absorbed by the atmosphere. All of that energy warms the planet and the atmosphere so that it gives off infrared radiation. The planet lives in equilibrium; the infrared radiation leaving our atmosphere is exactly the same amount of energy as that 71% of the radiation that it absorbs.

(If the planet absorbs more energy than it releases, the planet gets hotter. Hotter things release more infrared. When the planet is in equilibrium again, it stops getting hotter.)

So, what is the problem with CO_2 and other large molecules in the atmosphere? They absorb the infrared radiation instead of letting it escape into space. This means the planet must be hotter to maintain equilibrium.

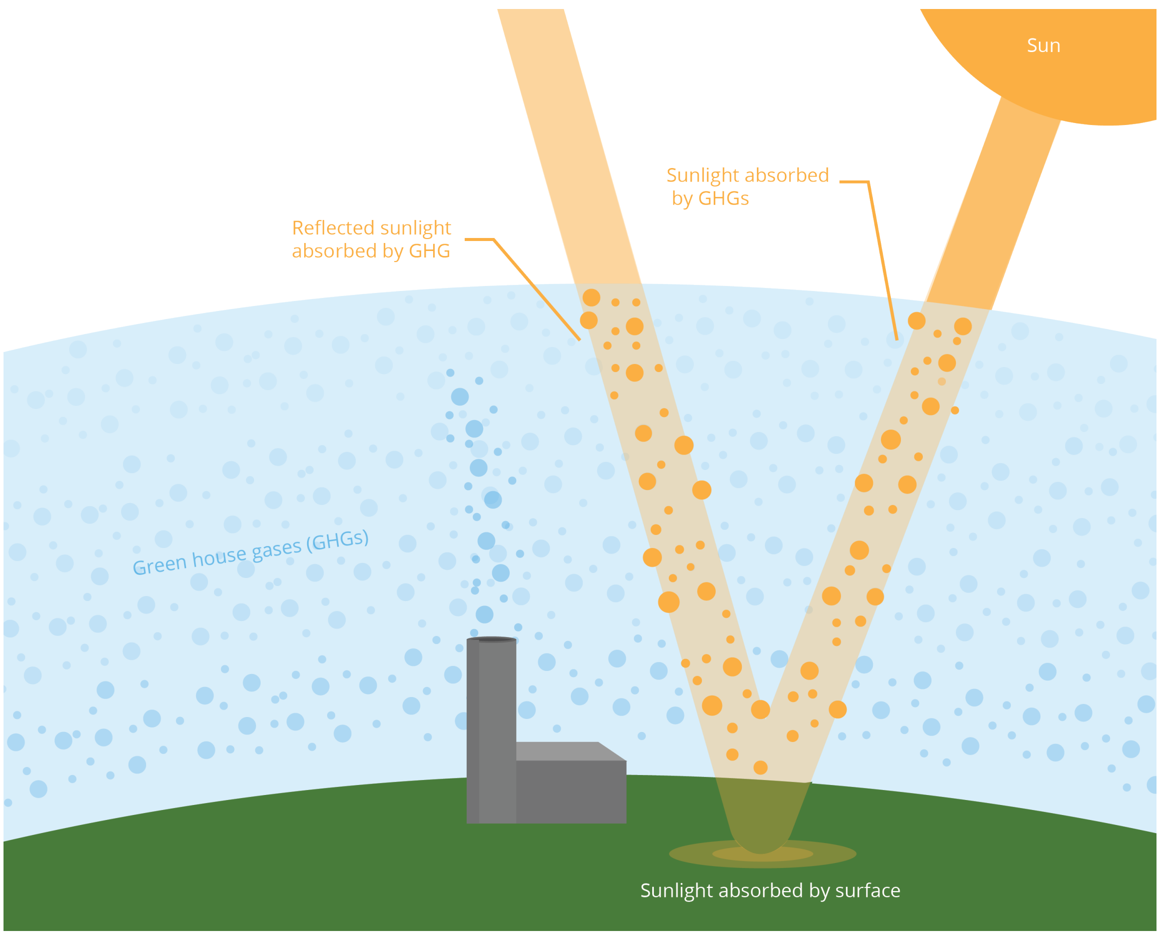

Figure 1.2: Greenhouse gas effects from the solar rays.

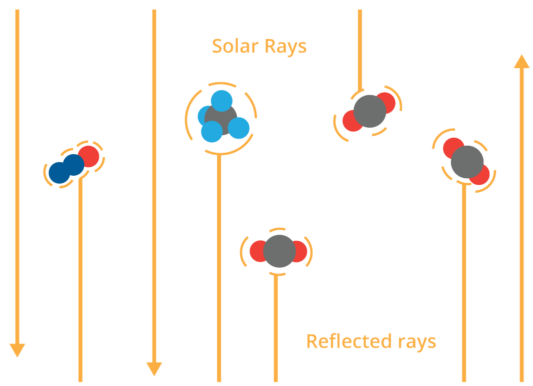

Figure 1.3: A zoomed in version of greenhouse gases.

The planet is getting hotter, and it is creating a multitude of problems:

- Weather patterns are changing, which leads to extreme floods and droughts.
- Ice and snow in places like Greenland are melting and flowing into the oceans. This is raising sea levels.
- Biomes with biodiversity are resilient. Rapidly changing climate is destroying biodiversity everywhere, which is making these ecosystems very fragile.
- In many places, permafrost, which has trapped large amounts of methane in the ground for millenia, is melting.

That last item is particularly scary, because methane is a large gas molecule — it absorbs even more infrared radiation than CO_2. As it escapes the permafrost, the problem will get worse.

Scientists are working on four kinds of solutions:

- **Stop increasing the amount of greenhouse gases in our atmosphere.** It is hoped that non-carbon based energy systems like solar, wind, hydroelectric, and nuclear could let us stop burning carbon. Given the methane already being released, it maybe too late for this solution to work on its own.
- **Take some of greenhouse gases out of our atmosphere and sequester them somewhere.** The trunk of a tree is largely made up of carbon molecules. When you grow a tree where there had not been one before, you are sequestering carbon inside the tree. There are also scientists that are trying to develop a process that pulls greenhouse gases out of the air and turn them into solids.
- **Decrease the amount of solar radiation that is absorbed by our planet and its atmosphere.** Clouds reflect a lot of radiation back into space. Could we increase the cloudiness of our atmosphere? Or maybe launch mirrors into orbit around our

planet?

- **Adapt to the changing climate.** These scientists are assuming that global warming will continue, and are working to minimize future human suffering. How will we relocate a billion people as the oceans claim their homes? When massive heat waves occur, how will we keep people from dying? As biodiversity decreases, how can we make sure that species that are important to human existence survive?

What are the greenhouse gases and how much does each contribute to keeping the heat from exiting to space? These numbers are still being debated, but this will give you a feel:

Water vapor	H_2O	36 - 72 %
Carbon dioxide	CO_2	9 - 26 %
Methane	CH_4	4 - 9 %
Ozone	O_3	3 - 7 %

Notice that while we talk a lot about carbon dioxide, the most important greenhouse gas is actually water. Why don't we talk about it? Given the enormous surfaces of the oceans, it is difficult to imagine any way to permanently decrease the amount of water in the air. Additionally, a great deal of water in the air is in the form of clouds, which help reflect radiation before it is absorbed.

This is a draft chapter from the Kontinua Project. Please see our website (`https://kontinua.org/`) for more details.

Appendix A

Answers to Exercises

Answer to Exercise 1 (on page 1)

$$\frac{300 \times 10^6}{5.66 \times 10^{14}} = 530 \times 10^{-9} = 530 \text{ nm}$$