MODULE 2: Energy and Electromagnetic Radiation

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2.1 Changes in energy make things happen

What is "energy?" It's surprisingly hard to provide a common-language definition of this very common word.

Part of the problem is that the word is used (and abused) in so many ways, from "energy prices are way up," to "high-energy particles," to "I have no energy today," to "these crystals have awesome energy," to "her energy is just so negative!"

Part of the problem is also that the concept of energy is so very fundamental to the nature of reality that we can't unpack it much further.

"Jargon" is language with a layer of extra meaning that is used by certain specialists. Scientists use a lot of jargon, but we're not alone. Political philosophers mean something different when they use words like "liberal" than the average person. English professors attach loads of extra meaning to words like "postmodern."

Natural scientists (as opposed to social scientists) have a special definition of the word "energy."

We define energy as "the capacity to do work."

But then we also have a special jargon-y definition of "work" which is quite different from the everyday use of that simple word.

In physics, "work" is anything that requires "energy!"

We can think of energy as a capacity or a potential for things to happen, of for things to change. Making stuff happen requires the expenditure of this capacity. It takes energy to make stuff change its speed and direction, or to change its temperature, or to change its state from solid to liquid.

A profound application of this concept is that if you want to make something happen, you're going to have to expend some energy. Conversely, if you don't expend any energy, nothing is gonna change!

2.1.1 Energy can be transformed from one kind to another or moved around from place to place, but never created or destroyed

One of the most important aspects of the kind of energy scientists talk about is that it is **"conserved." By this we mean that the total amount of it is fixed.** Energy can't be created or destroyed.

Energy can move around. It can be transferred from one thing to another. For example, the energy in a wooden bat can be taken away and imparted to a baseball. Or the energy in a laser beam can be absorbed by a thermometer. The distribution of energy in space can change. For example, the heat in a pot of water can dissipate into a room, making the water colder and the room warmer. But even with all this moving around, the total amount of energy stays the same.

Energy can be transformed from one form to another. If I climb up on a chair, I have converted some muscular and "kinetic energy" into something called "gravitational potential energy." This means that there's a "potential" for the force of gravity to convert my height into the kinetic energy of me falling back to the floor.

If I then step off the chair and land on the floor the speed I attain on the downward trip represents precisely the gain in gravitational potential energy I achieved by climbing up on the chair in the first place. The total energy is the same, it just gets converted from muscles to height to fall speed.

You can follow the energy conversions arbitrarily far back or forward hrough a chain of causes and effects:

Where did the energy come from to lift me up on the chair? From reacting glucose with dissolved oxygen in the cells of my muscles.

Where did the glucose come from? From the bagel I ate for breakfast.

How did it get into the bagel? From wheat harvested last year in North Dakota.

Where did the wheat get the energy? From photosynthesis, a biological photovoltaic reaction that harvests photons emitted by the Sun!

Where did the Sun get it? Nuclear fusion.

And so on.

Similarly, where did the kinetic energy of my fall go after I hit the floor?

More muscle contractions. And vibrations in the floor. And sound. And a tiny but measurable rise in the temperature of the air in the room. And dissipating heat from the building to the outdoors. And emission of thermal radiation from the Earth out to space.

2.1.2 Kinds of energy: radiant (light), kinetic, potential, chemical

We will frequently consider several specific kinds of energy in this course.

Radiant energy takes the form of oscillations in electrical fields and magnetic fields that create one another at certain frequencies and propagate through space at the speed of light. Examples are the light your eyes capture when reading these words, the emission of radio waves by the phone in your pocket or on your desk, the sunshine warming your world and the invisible thermal emission cooling the Earth right this second. There's a measurable property of radiant energy that's in linear proportion to the frequency of the radiation. We say that blue light has higher energy density than red light, that X-rays are more energetic than UV, or that microwaves are less energetic than thermal infrared.

Kinetic energy is the energy of motion. A car has (way) more kinetic energy when it is speeding down a free-flowing highway than when it's sitting at a stoplight. The Earth has a lot of kinetic energy because it's orbiting the Sun at a speed that makes it take a year to go around once.

Kinetic energy is proportional to mass. A 5000 pound Ford F150 going 35 miles an hour has *twice as much* kinetic energy as a 2500 pound Toyota Yaris. Kinetic energy is also proportional to the square of the speed with which something is moving. A 2500 pound Toyota Yaris going 70 miles an hour has *four times* as much kinetic energy as the same car going 25 mph, and twice as much as the 35 mph truck.

There are multiple kinds of ***potential energy***. We considered gravitational potential energy above. It's the energy associated with something's vertical position relative to something else. It's important because we need to expend (convert) some other kind of energy to attain extra height, and height can be converted to kinetic energy by falling.

There is ***chemical potential energy*** when some material can undergo a chemical reaction to produce energy, usually as heat. The head of a match has a lot of chemical potential energy, but not as much (per unit mass or volume) as dynamite. A gallon of gasoline has so much chemical potential energy that it can push a carful of people and luggage hundreds of miles against the friction of the air and wheels and the road.

In a deep sense, chemical energy is really electromagnetic energy too, because its associated with charged electrons pulling on charged atomic nuclei and vice versa. Biology rides on chemistry rides on physics.

2.1.3 All energy on Earth comes from the Sun (nuclear fusion)

Almost all ***energy on Earth is derived from incoming radiant energy from the Sun.***

Radiant energy in the tropics is converted by absorption into evaporated water at the ocean surface and increased temperature in the atmosphere. Both of these forms of energy lift the tropical atmosphere against gravity, translating the latent and sensible heat in the air into gravitational potential energy. The higher center of mass of the tropical atmosphere allows it to "fall downhill" toward the winter pole, creating jet streams and storms in the temperate latitudes. Every breath of wind is derived from solar photons. Ditto for Colorado River water flowing downhill through the Hoover Dam and turning turbines to generate electricity for Las Vegas.

Photosynthesis is a fucking miracle! Solar photons interact with loosely-bound shared electrons in chlorophyll molecules, bumping them up to an "excited" state. They reset themselves by creating a microscopic electric current, oxidizing one neighboring molecule and reducing another to create chemical potential energy that's ultimately stored by converting inorganic oxidized carbon (CO2) from the atmosphere into reduced organic compounds (sugars, sap) in the plant and then used to construct leaves, stems, roots etc in which chemical potential energy is stored. Virtually every molecule of reduced organic matter is then oxidized back to CO2 by respiration, the reverse reaction from photosynthesis that liberates stored solar energy to facilitate almost every biological happening. A miniscule fraction or the stored chemical energy of photosynthesis gets preserved in fossils in the Earth's crust and can later be dug up as coal, oil, and gas. These tiny bits of stored solar energy are used to power modern civilization.

The first word of this subsection is "almost" because nuclear energy is the exception to the rule that all Earthbound energy is derived from Sunshine.

2.1.4 Internal energy is molecular motion (temperature)

We considered the kinetic energy of macroscopic motion before, and there's also boatloads of kinetic energy way down at the microscopic scale of molecules and atoms. Molecules bounce around and collide with one another.

We can think of the kinetic energy of atoms and molecules as being "contained in" macroscopic matter. It's often called "internal energy" and we measure it as temperature.

Macroscopic temperature is directly proportional to the average kinetic energy of the microscopic particles that make up solids, liquids, and gases. Recall that kinetic energy scales with the square of velocity, so temperature measures the square of the average speed that the particles move around inside of things.

Temperature is measured in degrees. Almost everyone on Earth uses Centrigrade (a.k.a Celsius after a dead guy) as the unit of temperatre. Centigrade has 100 degrees between the boiling point (100 °C) and the freezing point (0 °C) of water. Only Americans use Fahrenheit degrees, which are about half the size (5/9) of a Celsius degree and start at an arbitrary point (0 °F is much colder than 0 °C). Both Celsius and Fahrenheit degrees can be positive or nbegative.

Absolute temperature can't be negative. It is measured in degrees Kelvin (after another dead white guy). Kelvin degrees are precisely the same size as Celsius degrees – that is, there are exactly 100 K between the boiling point and freezing point of water. But 0 K is absolute zero! There is no such thing as a temperature below 0 K because at 0 K the molecules have no more kinetic energy to lose! The freezing point of water is 273.15 K and the boiling point is 373.15 K. Room temperature (68 F = 20 C) is about 293 K. Normal human body temperature is 98.6 °F = 37 °C = 310 K. For some reason, when we use Kelvin temperature, we don't use the little "degree" sign (°). Inside my mouth it's 310 K, not 310 °K.

When air absorbs radiant energy (light), the energy of the radiation is converted to the kinetic energy of the molecules of air. This means the temperature of the air rises. Conversely you are always radiating energy into your surroundings, and you are always absorbing radiation from your surroundings (walls, floor, ceiling, desk, other people). If you absorb more radiant energy than you emit, your molecules will slow down (you'll cool off) and vice versa.

2.1.5 Energy can be moved around by conduction, convection, or radiation … Earth can only exchange energy by radiation to/from outer space

There are three ways energy can be transported through space: conduction, convection, and radiation.

Conduction is the transfer of internal energy from place to place through a material (usually a solid). At the microscopic scale, it's like slam dancing. Fast-moving molecules of hot stuff slam into slow-moving molecules of cold stuff. The molecules of hot stuff slow down (cool off) and the neighboring molecules of cold stuff speed up (warm). Internal Energy (heat) is transferred from the hot stuff to the cold stuff. Think of a wire held in a candle flame. The hot end in the flame transfers heat through the wire to the cold end and pretty soon you have to let go or your fingers will be burned (fast-moving skin molecules).

Convection is the bulk transfer of internal energy from one place to another, often as a result of gravity acting on blobs of stuff with different densities that result from differences in temperature. The classic example is a campfire. The air inside the fire is hot (fast-moving molecules), so it expands and becomes less dense. The air around the sides is more dense so it falls and displaces the air in the flames, which rises. The rising hot air carries its heat with it, transporting internal energy to the air above. Air blasting out of a hair dryer or jet engine also transports heat from place to place, so this is also convective heat transfer. So is a cold north wind in winter or the rising updraft at the center of a summer thunderstorm.

Pretty much every other form of energy transfer in the universe is radiation. Conduction and convection require matter, but radiation can transfer energy from place to place across empty space (vacuum). Since most of the universe is empty space, radiation is by far the most common form of energy transfer there is!

Most of what we experience as temperature in our daily lives is really radiation. You sense the temperature of a room via the balance of photons of radiant energy emitted by your skin flowing out vs the absorption of photons emitted by the walls and ceiling hitting you.

It is true that your skin also conducts heat to the air around you and vice versa, but this is ridiculously inefficient because a tiny envelope of air next to your skin adjusts to your temperature. We can sense convective heat transfer a lot more effectively than conductive heat transfer. Think of standing in a cold winter wind. You get cold because warm air is blown away from contact with your skin and clothing very effectively by the bulk motion of the air.

If you've ever standing in a lift line while snowboarding or skiing on a high mountain when the sun goes behind a high cloud, you have probably noticed the efficiency of radiant heat transfer. Sometimes a warm indoor room feels chilly if there's a large plate-glass window exposed to the outdoors at one end. Energy is radiating out of your skin more than it's being absorbed from the direction of that cold wall. Conversely a cold room can feel nice and cozy if there's a blazing fireplace 10 feet away.

The Earth floats in the vacuum of space. There can be no conductive heat transfer between the Earth and space because there's nothing out there to conduct heat to. Similarly, there's almost no convective heat transfer between the Earth and outer space because gravity holds the air and water down against the surface (thank goodness, or we couldn't breathe!).

So virtually all energy transfer between the Earth and the rest of the universe is via electromagnetic radiation. Now let's think about what that means.

2.2 Electromagnetic radiation: energy transfer through space

Electric fields which change intensity or direction give rise to magnetic fields and vice versa.

A classic high school physics demonstration has students wrap wire around a nail. When a battery is connected to the two ends of the wire, the spiral electric field created by the current flowing in the wire induces a magnetic field, so the nail becomes an electromagnet. Students use the magnetized nail to pick up paper clips or staples.

Then wire ends from the same wire-wrapped nail are connected to a light bulb. The nail is waved between the poles of a big magnet. As the coiled wire passes through the magnetic field, electric fields induced in the wire cause current to flow, lighting the bulb.

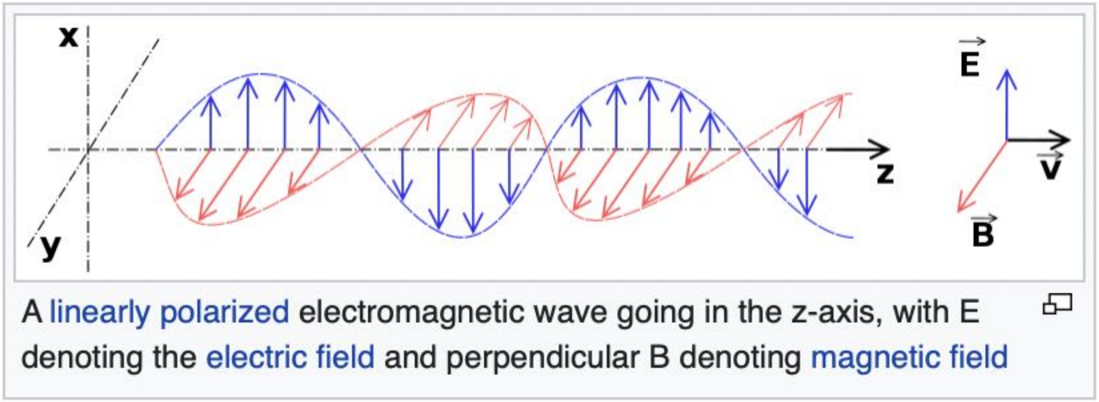
The nail, wire, and bulb are just used to reveal the relationships between changing electric and magnetic fields. The fields themselves don't require any material at all! Changing fields induce one another and the oscillating fields propagate through space on their own at the speed of light (3×10^8 m s^{-1}).

2.2.1 Electromagnetic Waves

Waves of oscillating electric and magnetic fields that create one another and propagate through space at the speed of light can be excited by the acceleration of charged particles as in the wire-wrapped nail example above.

Electromagnetic (EM) waves are also created when atoms and molecules transition from a more energetic state to a less energetic state. This is called ***fluorescence***, and it's characterized by emission and absorption at specific wavelengths/frequencies/colors whose energy levels correspond to the particular energy transition of the molecule. More about this next week in Module 3!

Finally, matter emits EM radiation across a huge range of wavelengths according to its temperature. This is called ***continuum*** radiation or ***incandescence***. I love that word!



A linearly polarized electromagnetic wave going in the z-axis, with E denoting the electric field and perpendicular B denoting magnetic field

Figure 1 Electromagnetic waves, illustrated in Wikipedia. The electric field (illustrated in red) is perpendicular to the magnetic field (illustrated in blue).

The ***wavelength*** of EM radiation is the distance traveled by the propagating electric and magnetic fields in the time it takes for the fields to cycle through their changes in strength and direction (see Figure 2.1 above). Wavelength is measured in meters. ***Frequency*** is just the number of waves that pass a given point in one second. Since EM waves all travel at the speed of light, the frequency is determined by the wavelength and vice versa. Short waves pass a point more frequently than long waves, so ***high-frequency radiation has short waves and low-frequency radiation has long waves***.

EM radiation can also be described as "particles" or "packages" of light called ***photons***. Neither the wave nor the particle descriptions is "more correct." Oddly, light is both a particle and a wave. In the particle description, photons of light have energy that's proportional to their frequency. High-***frequency (short wave) radiation packs a lot of energy into every photon. Low-frequency (long-wave) energy packs less energy per photon.***

2.2.2 The Electromagnetic Spectrum

The wavelengths of EM radiation vary across an incredible range of scales, from the size of atomic nuclei to the size of city blocks!

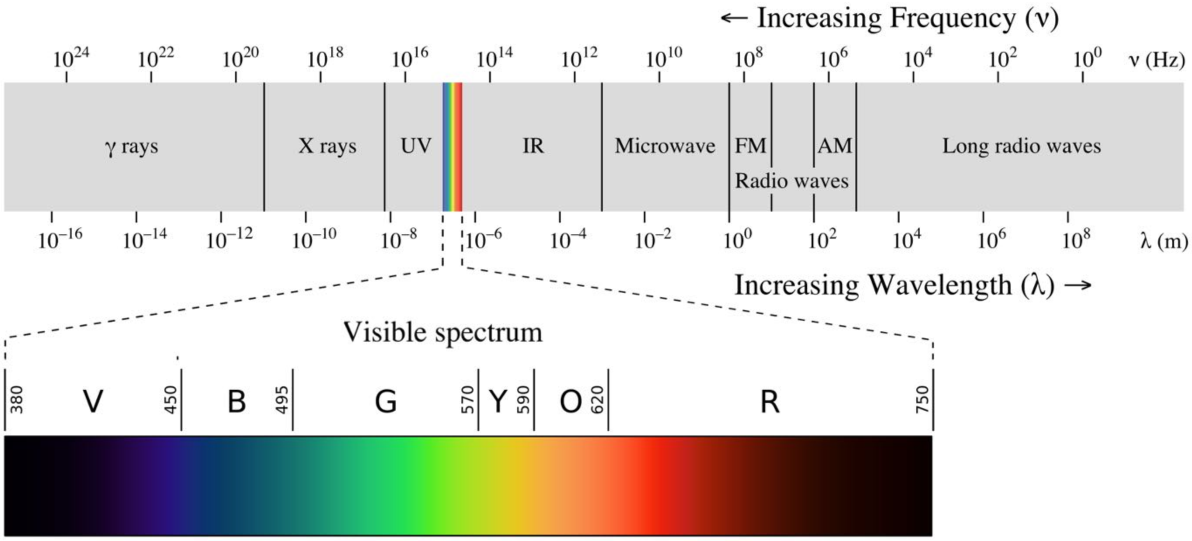


Figure 2: The electromagnetic spectrum, as illustrated in Wikipedia. Extremely short waves with the highest energy desnity are on the left and very long waves with the least energy desnity are on the right. The visible part of the spectrum is highlighted. Note that the scale is 100x longer than the tick to its left.

By Philip Ronan, Gringer - File:EM spectrum.svg and File:Linear visible spectrum.svg, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=24746679

Visible light is just a tiny part of the EM spectrum. We perceive minute changes in the wavelength of visible light as color. You can think of wavelength as a generalization of color, except that of course most of the colors of EM radiation lie WAY beyond the rainbow!

In the figure above, the colors of visible light are labeled with their wavelengths in nanometers, from about 400 nm to about 700 nm. A nanometer is a billionth of a meter. A millimeter (mm) is 1/1000 of a meter. A micrometer (µm, often called a ***micron***) is 1/1000 of a mm. And a nanometer is 1/1000 of a micrometer.

So visible light has really really tiny waves: green light has waves that are only about half of a thousandth of a millimeter long (500 nm)! Red light has waves that are a bit longer (700 nm) and blue light has waves that are a bit shorter (400 nm). Any ***EM radiation whose waves are longer or short than this range (400 nm to 700 nm) is invisible*** to us.

Beyond the red lies the infrared (IR) part of the spectrum. Because the energy density of EM radiation is proportional to its frequency, the ***interaction of IR with matter is weaker*** than for visible light. We can feel IR rays as heat, but IR is too weak to perform the electrochemical magic in our retina to make it visible to us.

Beyond the violet lies the ultraviolet (UV) part of the spectrum. UV rays are more powerful than visible light. ***They literally burn us!*** They cause sunburn, cataracts, and skin cancer. Our eyes have shielding at the front to stop these rays completely so they can't damage the sensitive retina in back.

Generally, the size of stuff that interacts with EM radiation is around the size of the waves.

On the high-energy (short wave) end of the spectrum, past the UV is EM radiation we call X-rays and gamma rays. X-rays are about the size of an atom. They can pass right through solid objects and can cause cancer. Gamma rays are even smaller, about the size of an atomic nucleus! They are so energetic that they can blast molecules apart and even split atomic nuclei.

On the low-energy (long wave) end of the spectrum, beyond the IR are microwaves and radio waves. The radio waves used for telecommunications are up to the size of football fields. That's why TV and radio broadcast antennas have to be so tall.

2.3 Thermal (Blackbody) Radiation

All matter emits thermal radiation according to its temperature. Hot stuff emits way more thermal radiation than cold stuff, and the peak wavelengths emitted are shorter the hotter something is. This means ***that hot things emit a lot and tend toward bluer (or UV) colors, while cooler things emit less and tend toward redder (or IR) colors***.

Thermal radiation is also called ***blackbody or continuum radiation***, and it comes in literally all wavelengths. The intensity of EM radiation emitted by objects varies according to wavelength in a very characteristic way called the Planck distribution after the German physicist Max Planck who first described it.

A ***blackbody*** is an idealization, a concept. It absorbs all EM radiation that hits it, regardless of wavelength. And it emits radiation according to the Planck distribution for its temperature. Almost all solid objects behave almost precisely as blackbodies. They don't have to appear black. A rock is a blackbody (close enough). So's a flower. I'm a blackbody. You too.

Figure 3 below shows variations of the intensity of thermal radiation emitted at each wavelength for blackbodies at a bunch of very high temperatures (indicated in Kelvin, K). A hotter blackbody emits more radiation at every wavelength than a colder blackbody. All blackbodies have spectra that are very steep on the short-wavelength end and then tail off gradually toward longer waves. The peak radiation from a hotter object has shorter waves than the peak radiation from a colder object.

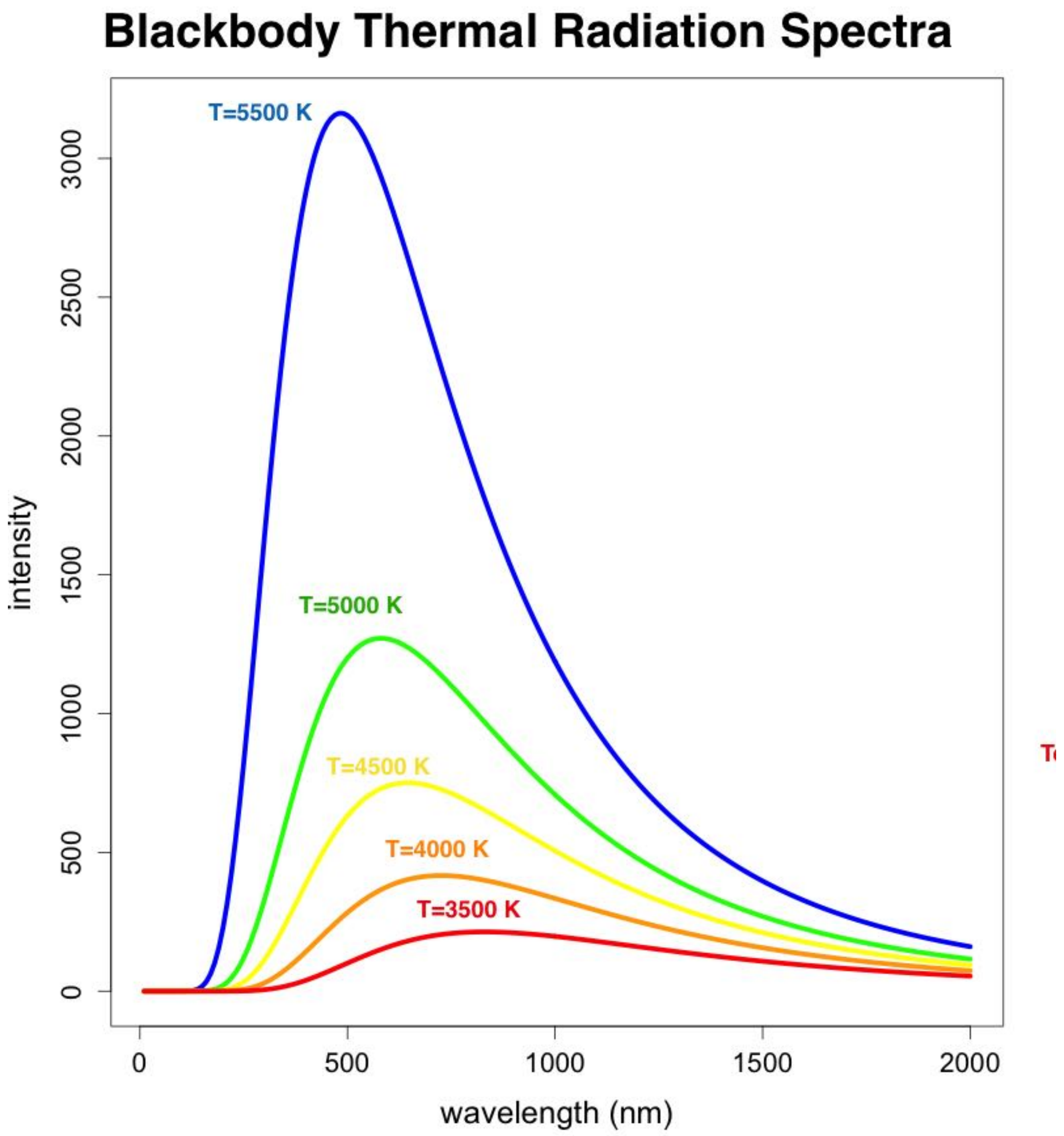


Figure 3: Thermal emission spectrum (Planck curves) for blackbodies at a range of temperatures. Remember that visible light has wavelengths from 400 to 700 nm.

The surface of our Sun is about 5800 Kelvin, so its emission spectrum is similar to the tallest curve shown above in Figure 3. Its emission is strongest right in the middle of the visible part of the EM spectrum (around 550 nm). This is no accident! Animals on Earth evolved eyes that are sensitive to the wavelengths of light emitted by the star that illuminates our world.

Stars that are cooler than our Sun emit radiation more like the other curves in Fig 3. They look progressively more orange and red as the temperature drops. Commercial lightbulbs are labeled with “color temperatures” like this. A bulb with color temperature of 6500 K will be a bit bluer than daylight. A “warm white” bulb that mimics old-fashioned tungsten filaments emits with a color temperature of around 2700 K like a red star.

Most objects on Earth are MUCH cooler than the Sun (thank goodness!). Room temperature is about 300 Kelvin, so about 20x cooler than the Sun. Therefore, the peak thermal radiation emitted by everyday objects such as desks, walls, and people has waves about 20x longer than the radiation emitted by the Sun. We don't glow (incandesce) in visible light like the Sun or the filament of an old-fashioned light bulb. Rather we glow in the infrared, with wavelengths that peak around 10 microns (μm) compared to 0.5 μm for Sunlight.

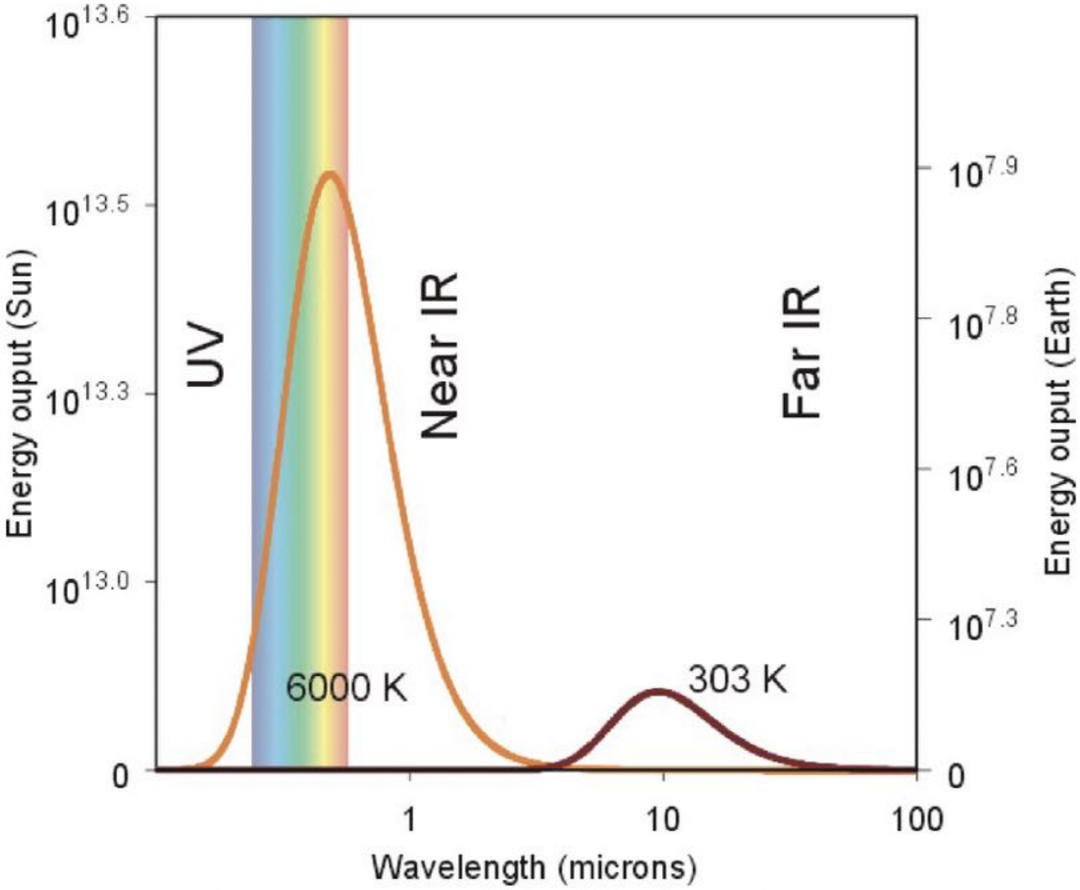


Figure 4: Comparing the thermal emission of the Sun (left scale) to tthat of the Earth (right scale). The Sun is about 20x hotter so emits most of its radiation at wavelengths 20x shorter. Figure from Schnmittner (OER)

The Earth's climate system absorbs energy mostly as visible radiation (from the Sun) and then emits it as thermal infrared (IR) radiation. Incoming energy is hot and short-wave (around half a micron), whereas outgoing energy is cool and long-wave (around 10 microns). The emission temperature of the Earth adjusts until the outgoing energy exactly balances the incoming energy.

The total rate at which objects lose heat energy by thermal radiation is equal to the area under the Planck curve. It turns out that this ***total rate of heat loss is proportional to the fourth power of the temperature*** (in Kelvin). This means the rate of radiative heat loss is *extremely* sensitive to temperature – a little difference in temperature makes a big difference in radiation!

The total rate at which EM energy is radiated (lost) from blackbodies (meaning most everything) is a very important quantity in climate science. we call this rate of heat loss a "flux" so we abbreviate it with the letter *F*. It can be calculated very easily from absolute temperature using the following formula

$$F = \sigma T^4$$

This is called the ***Stefan-Boltzman Law***. There aren't many equations or formulas in this course, and there are even fewer that it's worth actually memorizing. But this is one of those rare things you probably ought to memorize!

In the formula above, the weird letter ***o*** with a line off the top-right is the lowercase Greek letter sigma (σ). T is temperature, and it must must must be in Kelvin (never Fahrenheit or Celsius). Sigma is called the "Stefan-Boltzman constant" and it's really just a number that we measure by dividing flux by T^4. It's "empirical," meaning its value is determined by experiment. We have to include it to make the units work out.

The Stefan-Boltzman Law says that objects emit energy at a rate proportional to the 4th power of their temperature. That is, T x T x T x T. This means if the temperature doubles from T to 2T, the rate of cooling increases to (2T) x (2T) x (2T) x (2T) = 16 T. ***Something twice as hot emits 16x as much radiation***! Holy smoking crater Batman!

2.2.4 Units of Energy and Power

As we've discussed, energy is hard to define. In the International System of measurement, ***energy is measured in units of Joules*** (once again named after some dead guy). We abbreviate Joules as J.

An older energy unit that still knocks around in daily life is the calorie. A calorie is the amount of heat required to warm 1 gram of water by 1 degree Celsius. There are 4.186 Joules in a calorie. This gets even more confusing because the "nutritional calories" in our food are actually 1000 "real" calories. They are formally called kilocalories (kcal), and there are 4186 J in a kcal.

Physicists call the rate at which energy is absorbed or emitted or used up POWER. This is a special definition of an ordinary English word (that is, "jargon"). Because it's a change of energy over time, power has the units of Joules per second (J/s or J s^{-1}). We use this unit a LOT, so it gets its own name: "***Watt***." (again with the dead white guys). Try to remember that

1 Watt is defined as 1 Joule per second

$$\mathbf{1W = 1\ J\ s^{-1}}$$

Because climate science is concerned with the energy transfer between the Sun and the Earth and the rest of the universe, the numbers of Joules and Watts are ridiculously huge. So we usually divide them by the area over which they apply and write power (rates of energy change) in ***Watts per square meter (abbreviated W m^{-2}).***

Now that we know about units of measure, let's return to the Stefan-Boltzman Law.

Remember the empirical coefficient σ? It's just a measured number. The value of σ is

$$\sigma = 5.67 \times 10^{-8}\ \mathrm{W\ m^{-2}\ K^{-4}}$$

We would read that line aloud like this "five point six seven times 10 to the -8 Watts per square meter per Kelvin to the fourth power." Sometimes we write numbers like this in "exponential notation" as 5.67e-8 W m^{-2} K^{-4}.

(You certainly don't have to memorize the Stefan-Boltzman constant, but it's actually very easy because it's like counting "five six seven eight.") You need to be able to look it up or ask Google or Siri what the value is, because we use it all the time.

2.3 Solar Radiation

The Sun is really hot and really bright, but you knew that!

If you had a square of black cardboard that was 1 meter on a side and you somehow put it in orbit above Earth's atmosphere facing right toward the Sun, it would receive 1361 W m^{-2}. Students these days are too young to remember 100 Watt light bulbs but jeez-louise that's a lot of light! Thirteen and a half 100W bulbs crammed into every square meter!

Now obviously the whole Earth doesn't get that much power from the Sun. For starters, it's night on half the Earth at any given time. Even in the daytime there's only one tiny point where the Sun is directly overhead. Every other location the Sunshine comes in at an angle, so it gets spread out and solar power contributes fewer Watts to each horizontal square meter. Think about how wimpy the Sun feels at sunrise vs noon or in mid-winter vs mid-summer. That's all about the angle at which the beams of solar radiation hit the surface.

Besides geometry, a lot of solar power is lost by reflecting off clouds and dust particles. And a bunch more gets absorbed by gases and particles in the atmosphere (Figure 5 below). Above the atmosphere, the spectrum of Sunlight (yellow shading in Fig 5) is very close to that of a blacxkbody emitting at 5800 Kelvin (black line in Fig 5). But sunlight reaching the surface on a sunny day (red shading in Fig 5) has a bunch of missing wavelengths/colors. These dropouts in the solar spectrum are a result of sunlight being absorbed by specific gases in Earth's atmosphere, especially ozone (O3) and water vapor (H2O) as indicated in the Figure.

Much of the incoming power (44%) of sunlight is in the visible part of the EM spectrum, which is why it's visible. Only about 7% of solar power arrives in the UV, but it's dangerous to living things. The rest (49%) is in the invisible infrared, but most of that solar IR is in much shorter wavelengths (0.7 to 2 μm) than the thermal IR emitted by the Earth (around 10 μm).

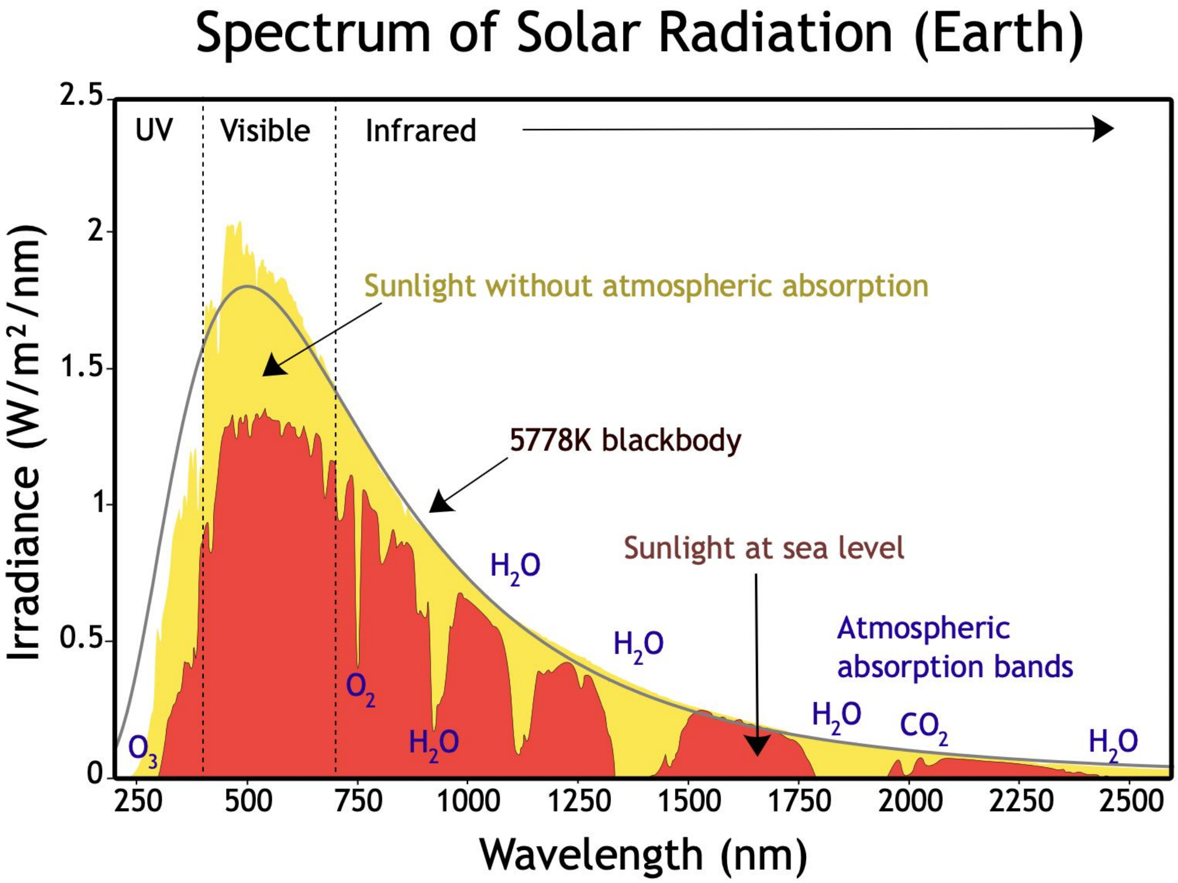


Figure 5: Solar irradiance spectrum above atmosphere (yellow) and at surface (red). Extreme UV and X-rays are produced (at left of wavelength range) but comprise very small amounts of the Sun's total output power (= area under the curve).Figure by Robert Rodhe published in Wikipedia.

2.3.1 Distribution of Solar Power in the Climate System

Incoming EM radiation can be reflected, absorbed, or transmitted. Sunlight that's reflected by molecules or particles in the air is called "scattered" because it doesn't always go right straight back up to space. It gets scattered in every direction, pinballing its way around and bouncing from molecule to particle in zillions of collisions before it either gets absorbed or is lost to space.

Shorter (bluer) waves of light scatter much more efficiently than longer (redder) waves. That's what makes the sky blue – all that scattered blue sunlight. It's also what makes sunsets orange and red – the loss of all that scattered blue light that's no longer in the straight path from the Sun to your eyes.

Sunlight in the atmosphere can be absorbed (converted to heat) by dark-colored particles like dust or soot and also by droplets of liquid water (clouds). About 19% of the incoming solar power reaching the Earth is absorbed in the atmosphere like this.

Table 1: Albedos of some common surfaces (from Wikipedia)

Surface	Typical albedo
Fresh asphalt	0.04
Open ocean	0.06
Worn asphalt	0.12
Conifer forest	0.08 to 0.15
Deciduous forest	0.15 to 0.18
Bare soil	0.17
Green grass	0.25
Desert sand	0.40
New concrete	0.55
Ocean ice	0.50 to 0.70
Fresh snow	0.80

Solar power that reaches Earth's surface is either absorbed (converted to heat) or reflected. The fraction that gets reflected is given a special (jargon) name: albedo. Albedo varies from 0 (total absorption) to 1 (total reflection) and is often expressed as a percentage (0% to 100%). High albedo means bright and reflective.

The albedo of different materials (Table 1 at left) varies a lot, which can affect the climate by reflecting a lot of incoming sunshine back upward. Fresh snow cools the local climate by increasing the albedo of the surface.

Altogether, ***about 30% of incoming solar power is reflected back to space by a combination of atmospheric backscatter and surface reflection. This means the albedo of the Earth is 30%. Another 19% of incoming solar radiation is absorbed by particles and droplets in the atmosphere, so only about 51% of incoming solar power is absorbed by the Earth's surface (land, oceans, and vegetation).***