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Introduction to Modern Climate Change

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Chapter

3 - Radiation and energy balance pp. 34-47

Radiation and energy balance

The Earth's climate is a complex system. Luckily, we can still understand a lot about the climate even if we do not have an advanced degree in physics. In this chapter, I introduce the important physics that we need to know to understand the climate; in Chapter 4 I will use this physics to create a simple model of our climate.

3.1 Temperature and energy

Before we get into the physics of radiation and energy balance, it is useful to talk about the concept of *energy*. To a physicist, energy is the capacity to do work – such as lifting a weight, turning a wheel, or compressing a spring. The unit of energy most frequently used in physics is the *joule*, abbreviated as the letter *J*. Energy is sometimes expressed in units of calories, or cal; 1 cal = 4.18 J. A food calorie is actually 1,000 cal, also called a kilocalorie or large calorie (1 kcal = 1,000 cal or 4,184 J). If you go to Europe, the nutritional label on food packaging has the energy content of the food marked in joules rather than food calories. Thus, a bag of Cheetos with 300 kcal or food calories would instead be labeled as containing 1.3 MJ or megajoules. I prefer food labeled in food calories because 1.3 megajoules sounds more fattening than 300 calories!

Energy often moves from one place to another. The rate at which energy is moving is referred to as *power*. It is usually expressed in *watts*, abbreviated as the letter *W*. One watt is equal to one joule per second – that is, 1 W = 1 J/s – so a 60-W light bulb consumes 60 J of energy every second.

An analogy may help to illuminate the difference between power and energy. A gallon is a measure of a quantity of water, just like a joule is a measure of a quantity of energy. The rate at which water flows through the pipe is measured in, say, gallons per minute. An analogous flow of energy is expressed in units of watts (joules per second). As you will see in this chapter and the next, climate is all about energy flows, so calculations of climate physics generally focus on power.

An example: How much power does it take to run a human body?

A typical human consumes approximately 2,000 food calories (equal to 2,000 kcal) per day. We know that 2,000 kcal × 4,184 J/kcal = 8,368,000 J = 8.37 MJ. One day has 86,400 s (or seconds) in it, so dividing 8,368,000 J by 86,400 s, we get 97 J/s = 97 W. Thus, the typical human requires roughly 100 W to power his or her

body – about the same power required to run a typical light bulb. One horsepower (1 hp) is approximately 740 W, so another way to think about this is that it takes one seventh of a horsepower or so (0.14 hp) to run your body.

The *internal energy* of an object refers to how fast the atoms and molecules in the object are moving. In a cup of water, for example, if the water molecules are moving slowly then the cup has less internal energy than another cup in which the molecules are moving rapidly. In a solid, the movements of the atoms are approximately fixed in space by intermolecular forces – that is why it is a solid. The atoms, however, can still move small distances around their fixed position. The faster these atoms move about their fixed position, the more internal energy the object has.

This brings us to a concept that most people are familiar with: *temperature*. Temperature is a measure of the internal energy of an object. As an object's internal energy increases – and the molecules of the object speed up – the temperature of the object also increases. Thus, if you have two cups of water, one hot and the other cold, you can conclude that the water molecules in the hot cup are moving faster than molecules in the cup of cold water.

In Chapter 1, I introduced the Celsius temperature scale, which is frequently used by scientists. There is another temperature that is even more favored by physicists, and it is called the Kelvin scale. The temperature in degrees Kelvin is equal to the temperature in degrees Celsius plus 273.15 ($K = C + 273.15$). Thus, the freezing temperature, $0\,°C$, is equal to 273.15 K, whereas the boiling temperature, $100\,°C$, is equal to 373.15 K. "Room temperature" is $22\,°C$ or so, which is approximately 295 K. Most temperatures found in the Earth's atmosphere are between 200 K and 300 K, and the average surface temperature of the Earth (today, at least) is roughly 288 K.

Physicists prefer the Kelvin scale because temperature expressed in degrees Kelvin is proportional to internal energy. Thus, if the temperature doubles from 200 K to 400 K, then the internal energy of the object also doubles. If the internal energy of an object increases by 10%, then the temperature expressed in degrees Kelvin also increases by 10%. This means that an object at 0 K, also called absolute zero, has an internal energy of zero – meaning that the constituent molecules are not moving. Because of these important qualities, the physics equations introduced in this chapter and the next require energy to be expressed in degrees Kelvin. Thus, I will use Kelvin temperatures in my climate calculations, whereas I will primarily use Celsius temperatures descriptively.

3.2 Electromagnetic radiation

It has been recognized for a long time that the warmth of our climate is provided by the Sun. However, the Sun sits 150 million km away from the Earth, with the vacuum of space in between. How does energy from the Sun reach the Earth?
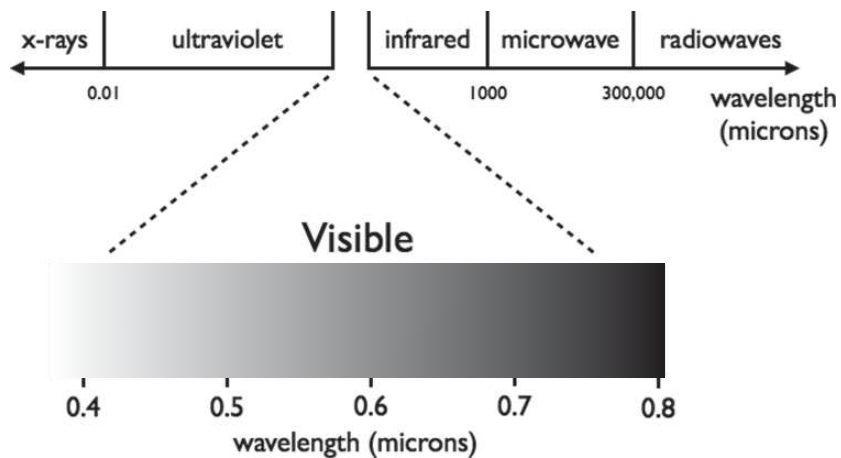
The electromagnetic spectrum. Note that the visible part makes up only a minor part of this spectrum.
(See Color Plate 3.1.)

Energy is transported from the Sun to the Earth by what is known as *electromagnetic radiation*.[1] Electromagnetic radiation includes visible light, like that put out by your desk lamp or the Sun; X rays that allow us to detect broken bones; microwaves that cook your dinner; and radio-frequency waves that bring calls to your cell phone and WiFi to your computer.

Electromagnetic radiation emanating from a flashlight, a lamp, your WiFi router, or the Sun is really a stream of *photons*, small discrete packages of energy.[2] As photons travel from Point *A* to Point *B* – such as from the Sun to the Earth – each one carries a small amount of energy, and this is how energy is transported from the Sun to the Earth.

Photons have a characteristic size, referred to as the *wavelength*, which determines how the photons interact with the world. Photons with wavelengths of between 0.3 and 0.8 micrometers, abbreviated as μm (a *micrometer* or micron is a millionth of a meter; a human hair is 100 μm or so in diameter), can be seen with the human eye – so we refer to these photons as *visible*. Within the visible range, the different wavelengths appear to the human eye as different colors (Figure 3.1). Humans see photons with wavelengths near 0.4 μm as blue, 0.6 μm as yellow, and 0.8 μm as red.

Photons with longer wavelengths, from 0.8 to 1,000 μm, are termed *infrared* – from the Latin for "below red" – because they are beyond the red end of the visible spectrum. Despite being invisible to humans, these photons play an important role in both the Earth's climate and in our everyday lives. Photons with wavelengths

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[1] When people hear the word *radiation*, they often think of nuclear radiation. Such radiation has very high energies because it originates from changes in atomic nuclei, and as a result this radiation can cause cancer and other medical problems. Electromagnetic radiation discussed here generally originates from changes in the atoms' electrons or from changes in the molecule's rotational or vibrational state, and therefore has far less energy – so it is generally not a health hazard. This is good, because you are surrounded by electromagnetic radiation right now.

[2] Electromagnetic radiation also behaves like a wave, but for this problem it is easier to think of it as a particle.

just below the human detection limit of 0.3 µm are called *ultraviolet* because their
wavelength is beyond the violet end of the visible limit.

Photons with wavelengths between 1,000 µm (1 mm) and 0.3 m are termed
microwaves, and photons in this wavelength range are used in many familiar applica-
tions, from cooking to radar. Wavelengths bigger than about 0.3 m are radio-frequency
waves, and they are used, as the name implies, in radio. The entire electromagnetic
spectrum is diagrammed in Figure 3.1.

The wavelength of the photon determines its physical properties. For example,
visible and infrared photons cannot go through walls, but radio-frequency photons
can. The human eye can detect visible photons, but not infrared or microwave photons.
When you get a full body scan at the airport, the machine is using either X rays or
microwaves – both wavelengths can go through clothes but are stopped by denser
materials such as flesh or a bomb. Finally, the atmosphere is transparent to visible
photons but less transparent to infrared photons; this fact has enormous implications
for our climate and will be discussed at length in Chapter 4.

3.3 Blackbody radiation

We know that both the Sun and the lamp on your desk are emitting photons. After
all, you can see the visible photons that they are emitting. They are not, however, the
only things around you that are emitting photons. In fact, *everything around you* is
emitting photons all of the time. So right now, you're emitting photons, as are the
walls of the room you're sitting in, your desk, your dog, this book. Everything.

If everything is emitting photons, then why doesn't everything glow like a light
bulb? The reason is that an object emits photons with a wavelength determined by the
object's temperature. Figure 3.2 plots *emissions spectra* for idealized objects called
blackbodies at three temperatures. An emissions spectrum is the amount of power
carried away from an object by the photons at each wavelength.

As shown in Figure 3.2a, photons emitted by objects at room temperature, approx-
imately 300 K, almost exclusively have wavelengths greater than 4 µm or so. These
wavelengths are outside the range that is visible to humans (indicated by the gray
shading in the figure). Thus, all room-temperature objects are emitting photons, but
you cannot see the photons because they fall outside the visible range. This is, in
fact, the origin of the term *blackbody*. At room temperature, the object appears black
because the photons emitted by these objects are invisible to humans.

Figure 3.2a shows that the peak of the emissions spectrum for a 300-K object
occurs near 10 µm and most of the energy being emitted by a room-temperature
object occurs through the emission of photons near this wavelength. It turns out
that there is a simple relation between the temperature of an object and the peak
of the object's emission spectrum. This relation is known as Wien's displacement
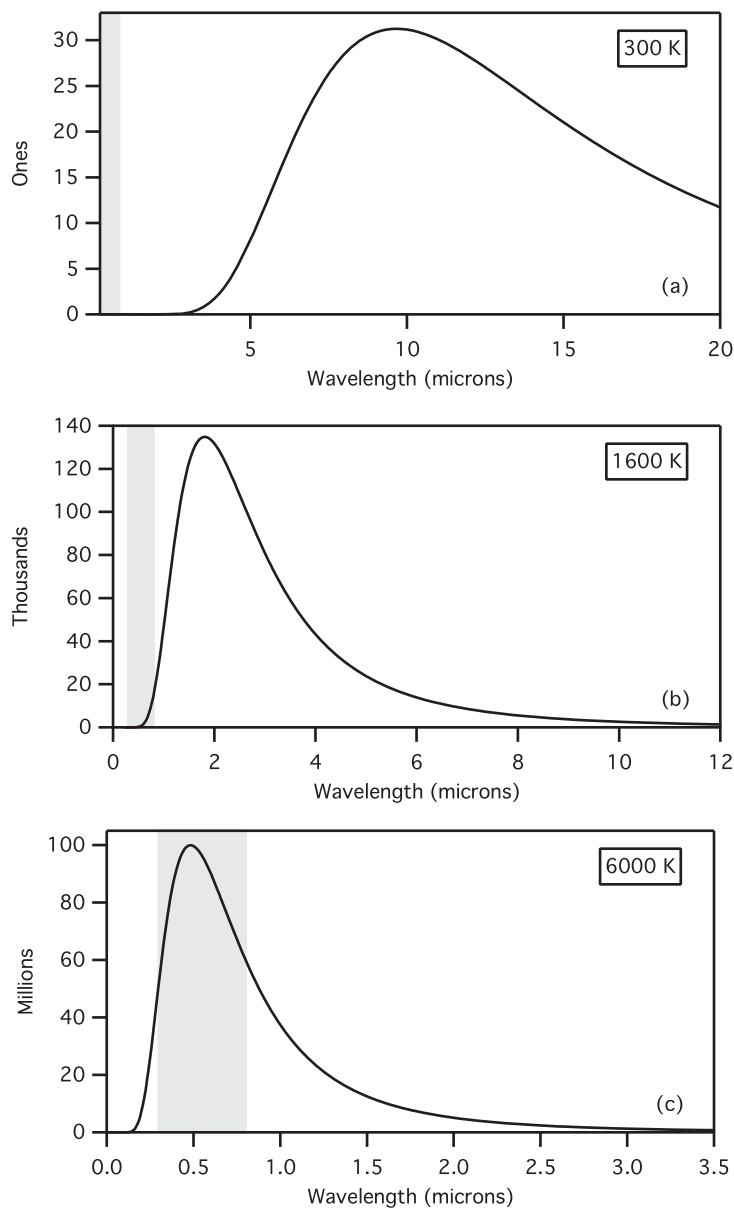law:

$$\lambda_{\text{max}} = \frac{3000}{T} \tag{3.1}$$

Power emitted at different wavelengths from objects (with surface area of 1 m^2) at three temperatures: (a) 300 K, (b) 1600 K, and (c) 6000 K. The vertical axes are in units of 1 W/μm, 1,000 W/μm, and 1 MW/μm of wavelength range, respectively. Gray bars show the wavelength range visible to human eyes.

Here λ_{max} is the wavelength of the peak of the emission spectrum and T is the temperature of the object. If we put 300 K into Equation 3.1, we get 10 μm, which is in good agreement with Figure 3.2. Note that T must be in degrees Kelvin and λ_{max} must be in micrometers in this equation. Had I used the temperature in degrees Celsius, for example, I would have calculated $\lambda_{max} = 3{,}000/24 = 125$ μm, which would be incredibly wrong.
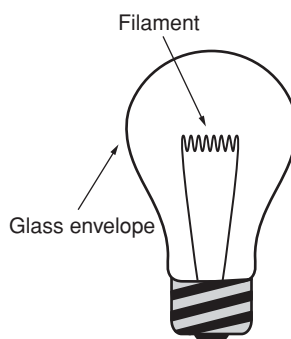
Fig. 3.3 A schematic of a typical incandescent light bulb.

Wien's displacement law also tells us that, as an object heats up, the peak of its emission spectrum moves to shorter wavelengths; in other words, λ_{max} becomes smaller. Figures 3.2b and 3.2c show that a 1600-K object has $\lambda_{max} = 1.9$ μm and a 6000-K object has $\lambda_{max} = 0.5$ μm.

It is also clear from Figure 3.2 that objects do not just emit photons at λ_{max}; they also emit them over a range of wavelengths around λ_{max}. So while $\lambda_{max} = 1.9$ μm for the 1600-K object, the object emits photons over a range of wavelengths from 0.7 to 10 μm. Because a small fraction of the photons emitted by this object have wavelengths smaller than 0.8 μm, which are visible and lie at the red end of the visible spectrum, humans will perceive a 1600-K object to have slight reddish glow to the object. In other words, this object is glowing "red hot." Blacksmiths use this fact to determine when a piece of metal has reached the appropriate temperature, and the necessity of seeing a faint glow from an object is one reason that blacksmiths tend to work in dim, low-light conditions.

For the 6000-K object, most of the photons emitted fall within the visible range. Our Sun is, to a good approximation, a 6000-K blackbody, and the distribution of photons from the Sun is closely approximated by the emissions spectra in Figure 3.2c. Because being able to see confers a strong advantage in surviving, it is no surprise that the eyes of humans and other animals have evolved to see this range of wavelengths. In fact, the human eye is maximally sensitive to light with a wavelength near 0.5 μm, which is the λ_{max} for a 6000-K blackbody. The chlorophyll molecule, the key component of photosynthesis, strongly absorbs photons in the visible range, showing that plants have also evolved to take advantage of photons emitted by the Sun.

Finally, if the photons emitted by room-temperature objects are not visible to our eyes, how can we see room-temperature objects, such as this page? What you see when you look at a room-temperature object are visible photons (emitted by the Sun or a light bulb or some other sight source) that have bounced off the object.

An everyday object that uses a lot of the concepts that we have discussed in this chapter is the humble incandescent light bulb. An incandescent light bulb consists of a glass envelope containing a small filament made of a metal, such as tungsten. When the light bulb is turned on, electricity flows through the filament, heating it to around 3000 K (Figure 3.3).

Typical lightbulb
3000-K filament

Wavelength (microns)
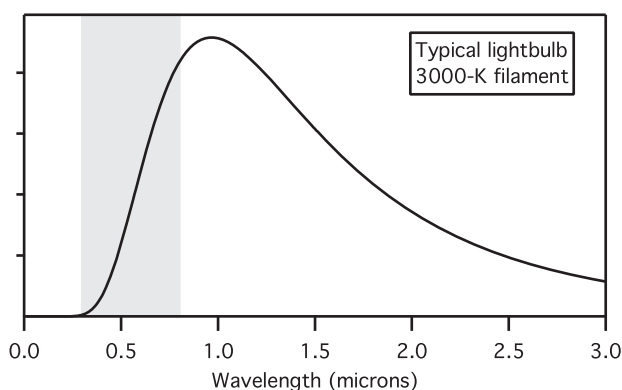
Fig. 3.4   Emissions spectrum for a 3000-K blackbody, a typical filament temperature for an incandescent light bulb. The numbers on the y-axis are omitted.

Figure 3.4 shows the wavelength distribution of photons emitted by a 3000-K blackbody. As the figure shows, the filament is hot enough that some of the photons emitted are visible – so humans will see the light bulb glowing and you can use it to light your room. However, nearly 85% of the photons emitted have wavelengths too long for the human eye to detect. These photons are basically wasted, and this makes incandescent light bulbs extremely inefficient as light sources.

One way for a light bulb to produce a higher fraction of visible photons – and therefore be more efficient – is to run the filament at a higher temperature. As described by Equation 3.1, this shifts the distribution of emitted photons to shorter wavelengths, thereby making a greater fraction of them visible to humans. The problem is that, as the temperature of the filament increases, the bulbs tend to burn out quickly. To get around this problem, the light bulb could be filled with halogen gas instead of the nitrogen and argon found in most incandescent bulbs. Because of chemical reactions between the halogen gas and the filament, these so-called halogen light bulbs can be run at temperatures several hundred degrees hotter than a regular incandescent bulb. This means that halogen light bulbs put out more photons in the visible range, making them more efficient than regular incandescent bulbs. Unfortunately, because the filament is run so hot, the light bulb itself also gets extremely hot, creating a fire and burn hazard.

As Figure 3.2 shows, the optimal temperature for the filament would be about the temperature of our Sun, nearly 6000 K, which provides the best overlap between blackbody emission and the human visual range. Unfortunately, it is impossible to run any kind of incandescent bulb at such temperatures because the filament would immediately vaporize and the bulb would be destroyed.

A better way to obtain high efficiency is to change the technology. The compact fluorescent light bulb, or CFL, uses a different technology (which I will not discuss here) to emit most of the bulb's photons in the visible wavelength range. Because of this, you get about the same amount of light out of a compact fluorescent as you do out of an incandescent bulb that consumes four to six times as much power. For example, a 12-W CFL will produce the same amount of light as a 60-W incandescent light bulb. In an effort to make the country more energy efficient, the U.S. Congress passed a law in 2007 phasing out standard incandescent bulbs in the United States by
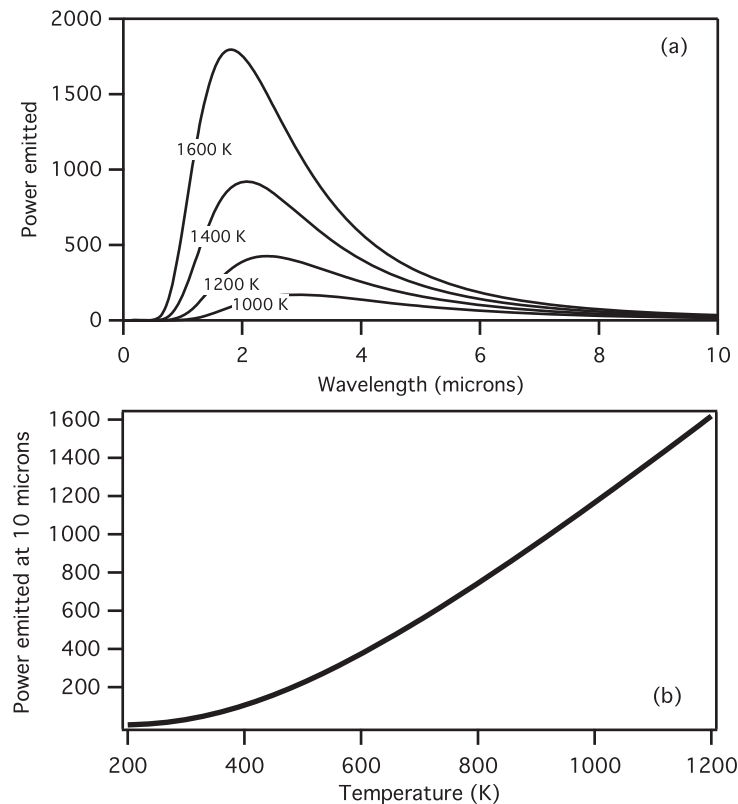
Fig. 3.5 Plots of (a) the distribution of power emitted by a blackbody at four different temperatures (1600, 1400, 1200, and 1000 K) and (b) energy emitted by a blackbody at 10 μm as a function of temperature. Plotted quantities are in (W/m^2)/μm.

2014. After that time, only energy-efficient CFLs and other new technologies will be available in stores.

Not only does the wavelength of emission change as an object's temperature changes, but the total power emitted also increases with temperature. We could see this in Figure 3.2, but it is more explicitly shown in Figure 3.5a, which shows four different blackbody-emission curves on a single plot. The plot shows that warmer objects emit more power than cooler objects at all wavelengths.

For a different view of this, Figure 3.5b plots the power emitted at 10 μm as a function of a blackbody's temperature. It is apparent that, as the temperature of the object increases, so does the power emitted at this wavelength. Infrared thermometers, which you can buy in any store, measure the emitted power at a single wavelength and then use a relation like the one in Figure 3.5b to estimate the temperature. Astronomers also use this principle to infer the temperature of distant stars and planets.

Figure 3.6 shows an image of a friendly dog in the infrared. To construct this image, the temperature is determined by measuring the power emitted at a particular wavelength and converting this to temperature. Bright colors in the image indicate warm temperatures and dark colors indicate cool temperatures. Like humans, dogs are mammals and their body temperature is around 38 °C. Fur is an insulator, however, so fur-covered regions of the dog are closer to room temperature than to body

Photo of Bailey the dog in the infrared, with colors assigned to different temperatures. Photo courtesy of New Mexico Tech Department of Physics. (See Color Plate 3.6.)

temperature. The parts of the dog that are not fur covered, however, such as the eyes, mouth, and the inside of the ears, are close to the dog's internal temperature. Note also the dog's cold nose.

As I already mentioned, the total power emitted by a blackbody increases with temperature. There is, in fact, a simple relation, known as the Stefan–Boltzmann equation, between the total power radiated by a blackbody and temperature:

$$P/a = \sigma T^4 \tag{3.2}$$

Note that P/a is the power emitted by a blackbody per unit of surface area, with units of watts per square meter; σ is the Stefan–Boltzmann constant, with $\sigma = 5.67 \times 10^{-8}$ (W/m^2)/K^4; and T is the temperature of the object in degrees Kelvin. If you multiply P/a by the surface area a of the object (in square meters), then you get the total power emitted by a blackbody, in watts.

An example: How fast is a room-temperature basketball losing energy by the emission of photons?

At room temperature, a blackbody is emitting $\sigma(300 \text{ K})^4 = 460$ W/m^2. A basketball typically has a radius of 5 in. = 0.13 m, so its surface area is therefore $4\pi(0.13 \text{ m})^2 = 0.2$ m^2. Thus, the total rate of energy loss from a room-temperature basketball as a result of blackbody photon emission is 460 W/m$^2 \times 0.2$ m^2, or 92 W. Thus, the amount of power being radiated is about the same as a typical light bulb. Of course, you cannot light a room with a basketball because the photons emitted by a basketball are outside the range that humans can see.

3.4 Energy balance

One of the cornerstones of modern physics is the first law of thermodynamics, which basically says that *energy is conserved*. What this means is that if some object

loses some energy, then some other object must gain that same amount of energy. Furthermore, because photons are just little packets of energy, the first law tells us that when an object emits a photon, the emitting object's internal energy must decrease. And because temperature is a measure of internal energy, the emission of a photon therefore causes the temperature of an object to decrease. Similarly, if a photon hits an object and is absorbed, then the energy of the photon is transferred to the object's internal energy and the object's temperature will increase.

An example: conservation of money

A good analogy for energy balance is money balance. If you gain 1 dollar, then someone else must be 1 dollar poorer – because money, like energy, cannot be created or destroyed.[3]

   Consider, for example, a checking account. Money, such as your paycheck or a birthday check from your grandmother, is periodically deposited into the account. At the same time, money is withdrawn, to pay for things such as rent or a cell phone bill. The change in your bank balance is equal to the difference between the total deposits (money in) and total withdrawals (money out). In equation form, we write this as follows: Change in balance = money in – money out. If money in exceeds money out, that is, your deposits exceed your withdrawals, then the change in balance is positive and your balance increases. If money out exceeds money in, then the change in balance is negative and your balance decreases. If money in and money out are equal, the change in balance is zero and your balance is unchanged. This is basically the calculation we do when we balance our checkbooks.

   If the energy flowing into an object (energy in) exceeds the energy flowing out (energy out), then the internal energy (and temperature) of the object increases. Written mathematically, this is as follows:

$$\text{Change in temperature} \propto \text{Change in internal energy} = \text{energy in} - \text{energy out}$$

Here the symbol $\propto$ means "is proportional to." Note the special case in which energy in and energy out are equal, in which case the internal energy and temperature are unchanged. We call this situation *equilibrium*.

   A good example that draws many of the concepts in this chapter together is the oven in your home. Most people, if asked how an oven cooks, would answer, "because it's hot inside." However, you may be surprised that the physics is subtler than you realize. Ovens do not cook because the air in the oven is hot – air is a terrible conductor of heat. Rather, ovens cook by infrared radiation.

   When an electric oven is turned on, electricity runs through a heating element. The element heats up, eventually reaching temperatures high enough that it radiates in the visible range, glowing a dark orange. At this point, the element is radiating an enormous amount of power, typically several thousand watts.

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[3] This rule does not apply to national governments, which can print money.

The photons emitted by the heating element are absorbed by the walls of the oven, heating them. When the walls reach a predetermined temperature, typically 350–450 °F (450–500 K), the oven is "preheated," and the cook puts the food, say a turkey, into the oven. Let's assume the turkey came out of the refrigerator and has a temperature of 3 °C or 276 K. At this temperature, the turkey is radiating 330 W/m². If the turkey has a surface area of 0.1 m², then the total power radiated by the turkey is 33 W.

The turkey is also absorbing photons from the oven's hot walls. The oven walls, at 375 °F (465 K), are radiating 2,650 W/m². The total surface area of the oven's six walls is approximately 1.3 m², so the total power radiated by the oven's wall is roughly 3500 W. Most of the energy radiated by the oven's walls misses the turkey in the middle and hits the other walls, and only a fraction of photons emitted by the walls hits the turkey. It turns out that the turkey absorbs photons emitted by an area of the walls equal to the surface area of the turkey, 0.1 m². Given that the walls emit 2650 W/m², that means that the turkey is absorbing 265 W of power.

Because the turkey is emitting 33 W but absorbing 265 W, the internal energy of the turkey is increasing and it is therefore warming. Eventually, the turkey reaches the temperature when it is considered "done" and the cook removes it from the oven. That's how a conventional oven cooks.

While the turkey is absorbing energy from the walls, by conservation of energy the walls must be losing energy and cooling down. As a result, the heating element of the oven has to turn on periodically to maintain the wall temperature at 375 °F. This occasional cycling back on of the heating element is familiar to any cook.

A microwave oven also cooks food by bombarding food with photons. However, instead of bombarding the food with infrared photons, a microwave oven bombards the food with microwave photons, which have longer wavelengths. For reasons that we will not go into here, microwave ovens cook faster because they are able to deliver higher rates of power to the food than a conventional oven can. In the example here, the oven is delivering 265 W of power to the turkey. By using microwaves, however, the oven is able to deliver 5 to 10 times that amount. The net result is that the food is heated more rapidly in a microwave oven than it is in a conventional oven.

I hope that you have a sense of the importance of the physics we have discussed in this chapter – it has a profound impact on your life and the world around you. It also plays a key role in climate. In Chapter 4, we will use the physics covered in this chapter to develop a simple model for the Earth's climate with which we can begin to understand how humans can alter the climate.

3.5 Chapter summary

- Energy is expressed in units of joules (J). Power is the rate that energy is flowing, and it is express in watts (W); 1 W = 1 J/s.
- Temperature is a measure of internal energy of an object and is frequently expressed by physicists in units of Kelvin. The temperature in degrees Kelvin is equal to the temperature in degrees Celsius plus 273.15.

- Photons are small discrete packets of energy. They have a characteristic size, known as the wavelength, which determines how the photons interact with matter. Photons with wavelengths between 0.3 and 0.8 μm are visible to humans; photons with wavelengths between 0.8 and 1,000 μm are known as infrared.
- Most objects emit blackbody radiation. The characteristic wavelength emitted by a blackbody is equal to $3,000/T$ (where wavelength is in micrometers and temperature is in degrees Kelvin). The total power emitted per unit area by a blackbody is equal to σT^4, where $\sigma = 5.67 \times 10^{-8}$ (W/m^2)/K^4 and temperature is in degrees Kelvin. Photons emitted by room-temperature objects are in the infrared and not visible to humans.
- When a photon is emitted by an object and then absorbed by another object, this process transfers a small amount of energy from the emitter to the absorber.
- If the energy received by an object by absorbing photons exceeds the energy lost by emitting photons, then the object's internal energy increases – and it warms up. The object cools off if the energy in emitted photons exceeds the energy received by absorbing photons.

Additional reading

For additional information about blackbody radiation, consult an introductory physics book. Most have sections on blackbody radiation.

Terms

Blackbody
Electromagnetic radiation
Emissions spectra
Energy
Energy balance
Equilibrium
Infrared radiation
Internal energy
Joule
Micrometer
Photons
Power
Temperature
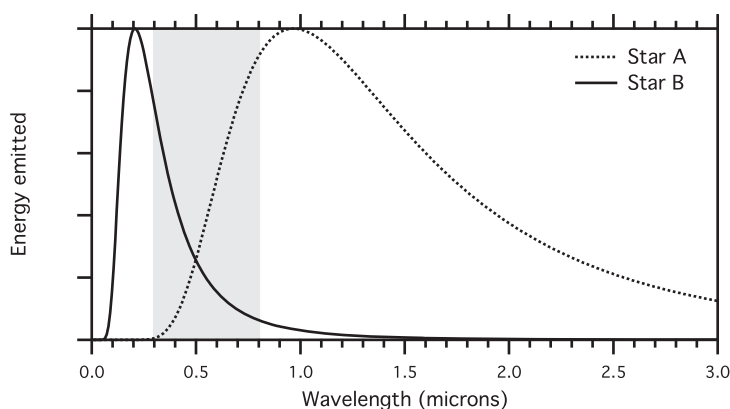Ultraviolet
Visible photons
Watt
Wavelength

Fig. 3.7   Emissions spectra of two hypothetical stars.

Problems

1. The temperature of an object goes up by 1 K. How much did it go up in degrees Fahrenheit and how much in degrees Celsius?

2. A sphere with a radius of 1 m has a temperature of 100 °C. How much power is it radiating? Remember that temperatures have to be converted to degrees K.

3. As a room-temperature object increases in temperature, it begins to glow. Describe the progression in colors as the object heats up. Ultimately, what happens to the glow if the warming continues to nearly infinite temperatures?

4. Consider two stars that have the spectra shown in Figure 3.7. Based just on the information provided in this plot, what are the colors and radiating temperatures of the stars? (The gray shading shows the range of wavelengths that humans can see.)

5. How much total energy (in watts) is the Sun radiating? It is a 6000-K blackbody with a radius of 700,000 km.

6. You can dim an incandescent bulb by decreasing the temperature of the filament. What do you think happens to the color of the bulb as it dims? Find a dimmer and test your hypothesis.

7. If you run a 60-W light bulb for 1 week, how many joules of energy have been consumed?

8. Why are incandescent light bulbs being phased out in many countries (including the United States)?

9. The Sun as a blackbody:
   a. The Sun is a 6000-K blackbody. At what characteristic wavelength does it radiate?
   b. At what characteristic wavelength does a blackbody at room temperature radiate?
   c. How much power per unit area is the Sun radiating?

10. Note that E_{in} is the energy being absorbed by an object, and E_{out} is the energy being radiated:

    a. If the temperature of an object is not changing, what does this tell us about E_{in} and E_{out}?

    b. If the temperature of an object is increasing, what does this tell us about E_{in} and E_{out}?

11. Your bank account has the same balance on April 1 as it did on March 1. Your friend suggests that this means that you did not deposit or withdraw any money for the entire month. Is that correct? Explain why or why not.