CHAPTER 6

Thermal Emission

Up to this point, we have considered only the *absorption*, *transmission*, and *reflection* of radiation incident externally on a medium. These interactions are sufficient for characterizing the disposition of shortwave (solar) radiation within the atmosphere, because its principal source, the sun, is external to the earth-atmosphere system. By contrast, the principal source of longwave radiation is thermal *emission* by the earth and atmosphere itself. Emission is the process by which some of the internal energy of a material is converted into radiant energy. This energy may either get reabsorbed at another location in the atmosphere or else escape to space, whereupon it is permanently lost, at least from the perspective of earthbound observers.

Normally, we are oblivious to the fact that we are constantly bathed in, and absorb, longwave radiation that is emitted by our surroundings, nor do we give much thought to the fact that our own bodies also lose heat energy via emission of radiation. One reason that we don't notice this is that the temperature of our skin and that of our surroundings is usually not too different; hence there is a near-balance between the heat we lose via radiation and that we absorb from our surroundings. Also, if there is any air movement at all (as is usually the case outdoors) then we tend to be more conscious of heat exchange with the air in direct contact with our skin, due to conduction, than that due to radiation.

The existence of thermally emitted radiation becomes more apparent to us when the temperature differences are larger. A wood-burning stove radiates heat that you can feel on your face from across a room. A car parked under a clear sky during the fall or winter can rapidly cool to the point that frost forms on the windshield, even if the free air temperature remains a few degrees above freezing. If an object becomes sufficiently hot, thermal emission may be great enough at the shorter wavelengths so as to be visible to the eye. The glowing embers in a fireplace or barbecue grill are one example; the white-hot filament of an incandescent light bulb is another.

It is possible to derive the relationship between temperature and thermal emission from first principles, based on the laws of quantum mechanics and statistical thermodynamics.[1] In keeping with the title of this book, we will instead go straight to the bottom line, explaining the general characteristics of thermal emission and giving you the tools to perform radiative calculations of the type most relevant to meteorologists.

Here, in words, are the key facts about thermal emission of radiation that you should be very comfortable working with by the time you finish this chapter. We will elaborate on these points, and provide the relevant formulas, in the subsequent subsections.

- An object having temperature T will generally emit radiation at all possible wavelengths. However, for any particular wavelength λ, there is a hard upper bound on the amount of that radiation. The function of T and λ that gives that upper bound is called *Planck's function*. The shape of Planck's function for several representative temperatures in the atmosphere is shown in Fig. 6.3. The mathematical details will be given shortly.

- For any given (absolute) temperature, Planck's Function has its peak at a wavelength that is inversely proportional to that temperature, a fact that is embodied in *Wien's Displacement*

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[1] See for example Appendix A of L02.

Law. Thus, peak emission from a cool object, like the earth, occurs at much longer wavelengths than that from a very hot object, like the sun.

- By integrating Planck's Function over all possible wavelengths, you get the *Stefan-Boltzmann law*, which states that the theoretical maximum amount of total (broadband) radiation that can be emitted by an object is proportional to the fourth power of its absolute temperature. Thus, doubling the temperature of an object leads to sixteen-fold increase in the maximum amount of radiation it can theoretically emit.
- Within any given band of wavelengths, a good absorber is also a good emitter. This fact is embodied in *Kirchhoff's law*. Thus, a perfect reflector (nonabsorber) emits no thermal radiation. A perfect absorber emits the theoretical maximum amount of thermal radiation, as described by Planck's Function.

I urge you to spend some time thinking about the above four points and committing them to memory. Once you have an intuitive grasp of these basic facts, your brain will be more receptive to precise mathematical re-statements of the same facts. You will also be less likely to use the mathematical formulas "blindly" in possibly inappropriate ways.

6.1 Blackbody Radiation

I just made several references to the "theoretical maximum amount of radiation" that can be emitted by an object. I also pointed out that a good absorber is a good emitter. In order for thermal emission from an object to actually achieve the "theoretical maximum," it must be a perfect emitter, which is to say, a perfect absorber.

An object that absorbs radiation perfectly is called a *blackbody*. In other words, it is a graybody for which the absorptivity $a = 1$. As such, it is an idealization that is seldom exactly realized in nature. Nevertheless, it is surprisingly easy to approximate a blackbody as follows:

Take a large, empty cardboard packing box (say, two feet on a side) and tape it closed on all sides. Then punch a small hole — one