Evaluation PHY555 Energy & Environment

Friday 16st December 2022

Part II, 5 points, recommended time 30 min

Note 1: Use pink paper sheets for your answers.

Exercise: Sky Radiator

By carefully tuning the optical properties of a material, it is possible to take advantage of radiative heat transfer in order to provide a cooling power with a passive system. The main idea is to take advantage of a spectral window where the atmosphere is almost transparent to radiatively expel heat towards space.

1. Demonstrate that, when a hot and a cold system are in contact, heat flows spontaneously from the hot to the cold system. What is required in a usual chiller to take heat away from the cold source towards the hot source?
2. Estimate from basic principles the solar irradiance (in W/m²) received by an absorber under direct sunlight on Earth.
3. Consider the absorber as gray-body (constant absorptivity ≤ 1). Estimate the steady state temperature of the absorber considering only the solar radiation as a power input.
4. According to the previous situation, what is the temperature of the absorber in the dark (for instance, at night)? Comment this result.
5. We now also consider that radiation emitted by the atmosphere, which we consider as a black body at ambient temperature. Estimate the atmospheric irradiance received by the absorber. What is now the temperature of the absorber in the dark?
6. Consider that the absorber has a given absorptivity in the 0.2 – 2 µm spectral region, and a (possibly) different absorptivity in the 2 – 20 µm. Show that in this simple model, the absorber cannot be colder than ambient temperature, regardless of the solar irradiance.
7. The atmosphere is actually not a black body, but shows transparency windows (ie spectral intervals with almost no absorptivity), notably in the 8-13 µm region. It is possible to take advantage of this feature to achieve a passive chiller – a system which spontaneously reaches temperatures 5K lower than ambient temperature, even under sunlight (Raman et al., Nature volume 515, pages 540–544 (2014)). Explain qualitatively how it is possible, and how this result can be compatible with question 1 and 4.

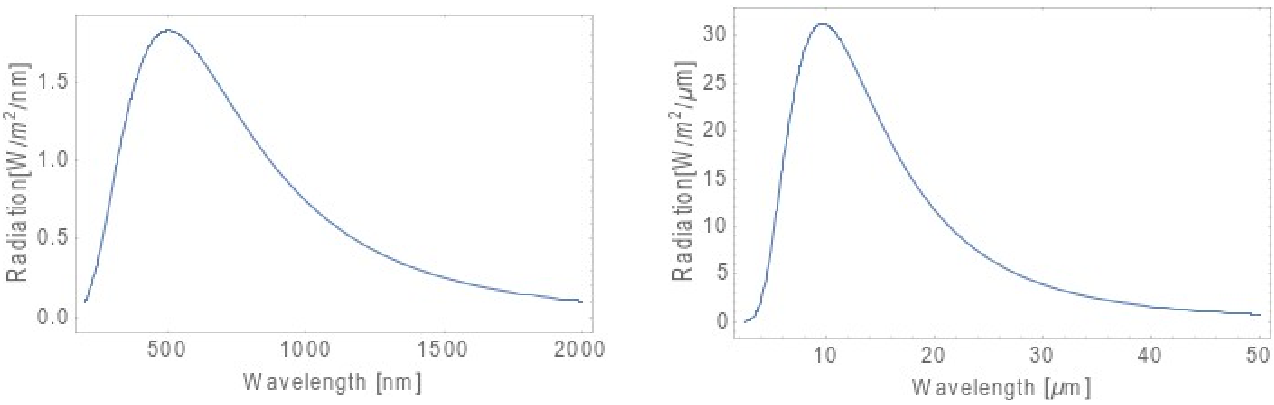

Figure 1: Blackbody radiation at the sun's temperature (left) and at ambient temperature (right).