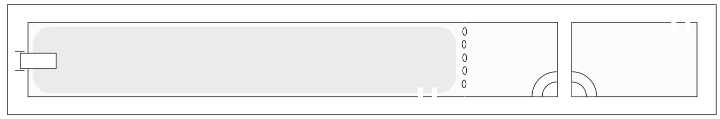
PhyzSpringboard: Intro to Thermal Radiation



Radiation is anything that radiates. Thermal radiation takes the form of electromagnetic waves. We will study electromagnetic waves in greater detail later in the course. Here are a few details to tide us over until then. An electromagnetic wave is an oscillation of electric and magnetic fields. Electromagnetic waves include radio waves, microwaves, infrared, visible light, ultraviolet light, X-rays, and gamma rays. They all propagate at the same speed, but vary from each other in their rate of oscillation (frequency).

An electromagnetic wave is emitted from any jiggling charged body. For example, if you rubbed a balloon on your head to charge it then shook the balloon up and down, it would emit electromagnetic waves.

1. What kinds of things emit electromagnetic waves? Consider the following.
   a. What are the smallest particles a substance is made of (that retain the chemical properties of the substance)?

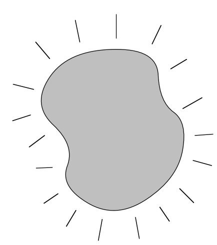
   b. Do those particles have jiggling charged bodies in them?

   c. How can the jiggling of those particles be reduced?

   d. Theoretically, how could the jiggling be stopped?

   e. What kinds of things emit electromagnetic waves?

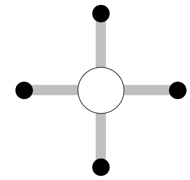
2. Consider a body made of many atoms (most bodies are made of many atoms) at room temperature.
   a. Will the body emit electromagnetic waves? Explain.



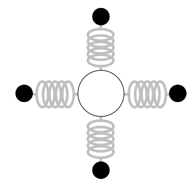
   b. i. Which atoms are responsible for emitting radiation that actually leaves the body?

   ii. What happens to the radiation emitted from the other atoms?

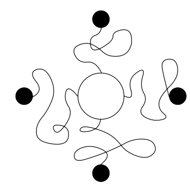
c. Some atoms have electrons that are tightly bound to the nucleus and some have electrons that are loosely bound. Consider the "artist's conception" of varying bond strength shown in the diagrams to the right.



i. How do the atoms vary in their ability to emit electromagnetic waves? Answer in words and pictures.

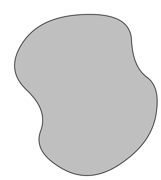


ii. How do the atoms vary in their ability to absorb electromagnetic waves? Answer in words and pictures.



This factor is called **emissivity.** It is denoted with an *e* and varies from a value of 0 if electrons are completely independent of their nuclei to a value of 1 if the connection is solid. Which arrangement is most similar to a silvery surface and which is most similar to a black surface?

3. Compared to the original radiating body, list three ways to change to body that would give it a higher radiation rate. Change only one characteristic of the body at a time.



a. One body that would emit radiation at a higher rate would be identical to the original body in every way except... (Answer using words and pictures.)

b. Another body that would emit radiation at a higher rate would be identical to the original body in every way except... (Answer using words and pictures.)

c. A third body that would emit radiation at a higher rate would be identical to the original body in every way except... (Answer using words and pictures.)

4. a. If the phrase, "the rate at which heat is radiated," were deemed too much to write, how could the expression be abbreviated using symbols?

b. Which physical quantities—if any—is the radiation rate directly proportional to and which—if any—is it inversely proportional to?

c. Collect the findings above and write a single proportionality. (I get hungry whenever I write this one)

d. To turn the rough proportionality into an equation, a few modifications must be made.
i. A constant of proportionality must be added to the expression. It is called the Stefan-Boltzmann constant. It is denoted with the lowercase letter sigma (σ) and has a value of $5.67 \times 10^{-8} W/m^2K^4$.
ii. The dependence of radiation rate on temperature is extraordinarily strong, as your instructor will now indicate.
iii. Take these modifications into account and write the equation.

This expression is called the **Stefan-Boltzmann Radiation Law.**

5. a. Use the expression above to determine the radiation rate of a black can (e=1.0) filled with 100°C water. The surface area of the can is $0.01 m^2$.

b. If your answer to the previous exercise was less than 1.0, consider the following question. Which would radiate at a higher rate: a can at 0°C or one at –273°C? Answer it qualitatively first, then quantitatively by calculating answers. what is the error in your calculated answer for the previous exercise and how can you correct it?

c. Determine the temperature of the can if it radiates at a rate of 100W.

5.a. 11W c. 375°C