Radiation as a Mechanism for Heat Transfer

Cody Petrie

Southern Utah University

Quiz

NO QUIZ TODAY

I was told that that my lesson can't have any effect on your grades

Radiation

What do you think of when you hear the word radiation?

Radiation

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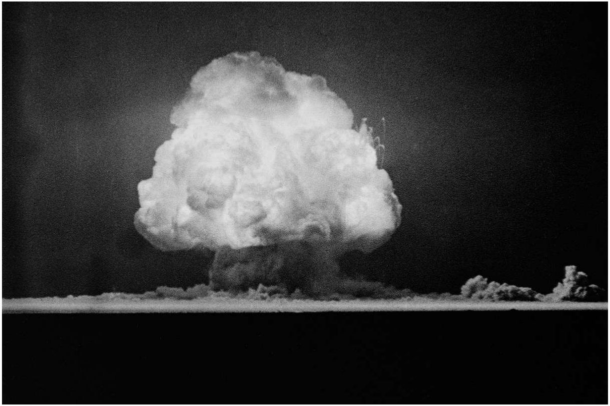

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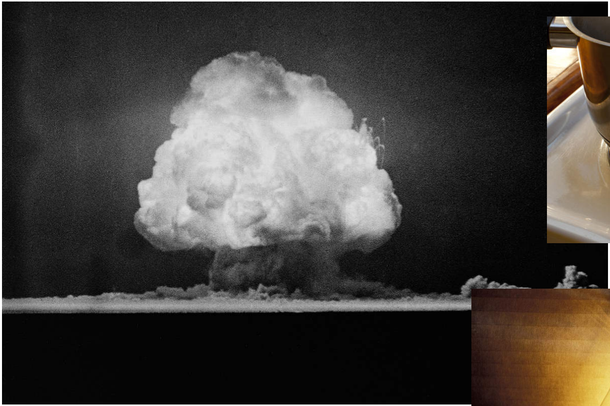

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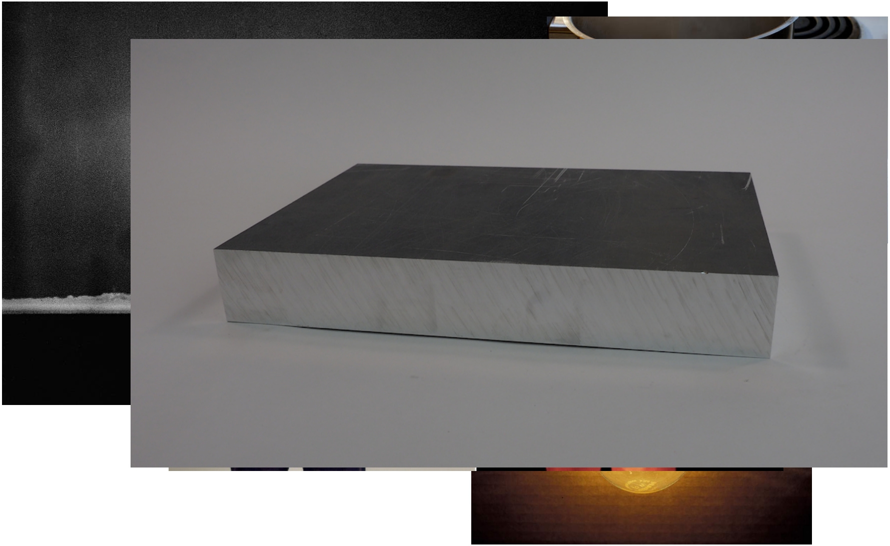

Review

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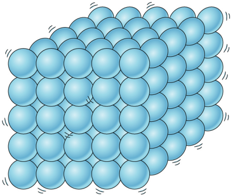

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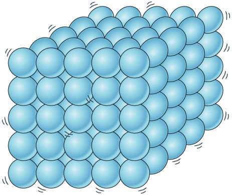
- What about **work** and **heat**?



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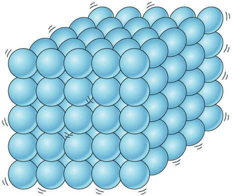

$$dW = \mathbf{F} \cdot d\mathbf{r}$$
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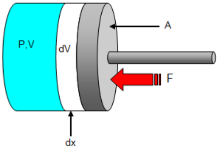

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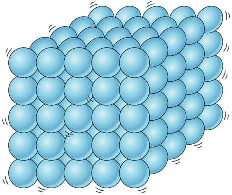

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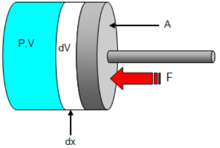
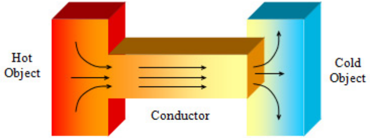
  - Heat is the flow of energy from one thing to another, usually because of a temperature difference.





First Law of Thermodynamics

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$$\Delta E_{\text{int}} = Q_{\text{added to}} + W_{\text{done on}}$$

Check for Understanding

I have a gas contained in a metal cylinder with a piston. I want to temporarily raise the energy of the gas contained in the cylinder. How should I do it and how much will it change the energy by?

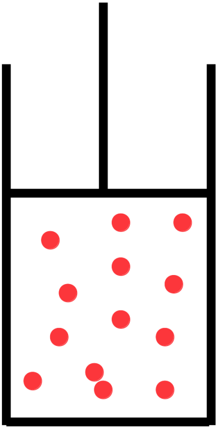
A. Push the piston down, $\Delta E\text{int} = \int_{V_i}^{V_f} PdV$

B. Push the piston down, $\Delta E\text{int} = -\int_{V_i}^{V_f} PdV$

C. Pull the piston up, $\Delta E\text{int} = \int_{V_i}^{V_f} PdV$

D. Pull the piston up, $\Delta E\text{int} = -\int_{V_i}^{V_f} PdV$

E. Quit and give up



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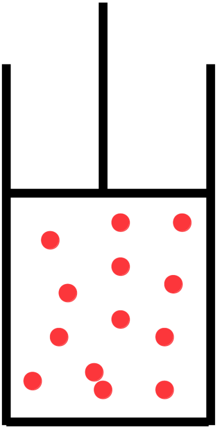
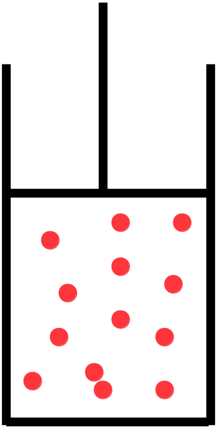


Check for Understanding - Again

Same situation, we want to add energy, but since we used a metal cylinder the piston rusted and won't move. What should we do now to add energy?

A. Keep pushing on the piston
B. Wait for a really long time for something to happen
C. Give up, but give the container a good hard kick to make yourself feel better



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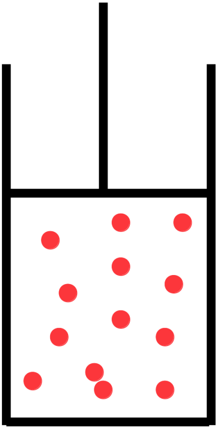
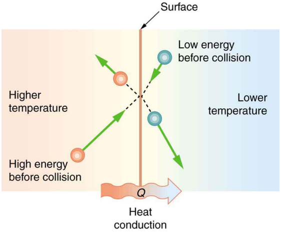
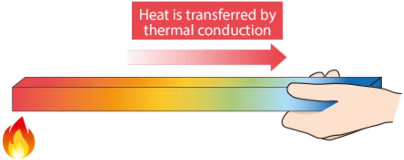


And this leads us into our next topic: heat transfer

- **Conduction:** Kinetic energy is exchanged between atoms and molecules as they collide.





Mechanisms for Energy Transfer

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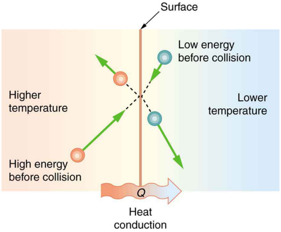
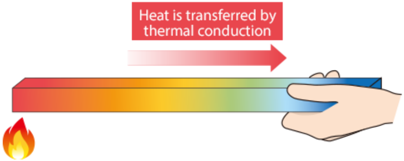
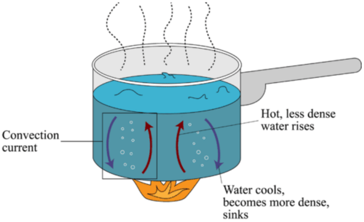


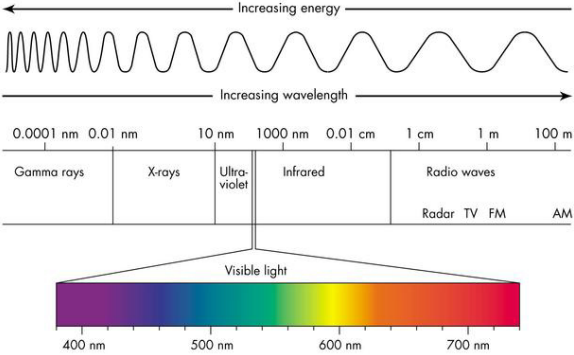


- **Convection:** Some bulk medium that has some energy is moving and carrying that energy with it.



Thermal Radiaton

- The third way in which an object can transfer/move energy is through **radiation**.
- All things radiate, but only things that radiate in the visible part of the spectrum "glow."



Thermal Radiation

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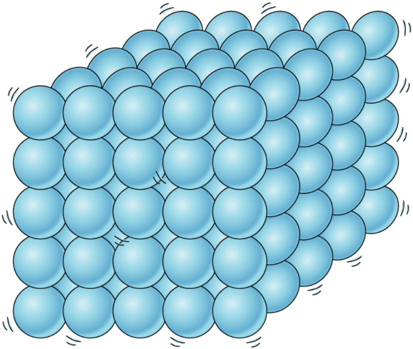
- Why do things radiate energy as Electromagnetic (EM) waves/radiation at all?
- It turns out that when charged particles change velocity they radiate energy as EM waves. The more they change their velocity the more energy they radiate.



In fact, absorbing EM waves (radiation from other things) will cause the particles of move around more, which in turn causes them to radiate more.

Thermal Radiation

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- Question for your group: Do you think a “hotter” object will radiate more of less **and why**?

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- In 1879 Josef Stefan studied how much power was radiated by hot platinum filaments and found that $P \propto T^4$.

- This is what we now call the Stefan-Boltzmann Law (Boltzmann discovered the same thing a few year after Stefan)

$$P = \sigma A e T^4$$

Stefan-Boltzmann Law

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- $\underline{e}$ is called the emissivity and it takes values from 0 to 1. Not all things are good at absorbing and radiating EM energy, so to account for this we experimentally determine how well things radiate, 1 being a "perfect" radiator and 0 doesn't radiate at all.

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- $\underline{T}$ is temperature in K.

Emissivity, e

- Another name for the emissivity is the absorptivity, which is the fraction of absorbed energy to indicent energy.

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- If an object is good at absorbing light then it must be good at radiating it (otherwise you would get a build up of energy).

This object likes to absorb bikes but doesn't like to radiate them.

Check for Understanding

Which of these has high and which has low emissivity?

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Low

High

Emissivity is how well an object absorbs EM radiation. The earth's soil has a high emmissivity of about $e = 0.95$.

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B. Most things prefer warmer temperatures.

C. If things radiate they also absorb radiation.

D. Everything is at absolute zero.

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In fact things only cool down because of radiation if they are a higher temperature than their surroundings. If $T_{\text{object}} = T_{\text{surroundings}}$ then they both radiate about the same amount and absor the same amount, so they lose and gain the same amount of energy.

$$P_{\text{net}} = \sigma A e \left(T^4 - T_0^4 \right)$$

Check for Understanding - Cool Nights

Why does the earth cool down at night given?

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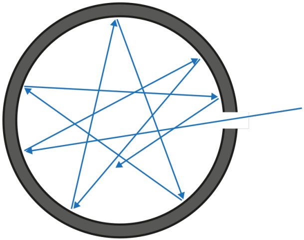
The earth loses energy at night because T_0 is the temperature of empty space but increases in temperature during the day because T_0 is affected by the presence of the hot sun.

Black Body

- An object that is a "perfect" absorber (and emitter) has $e = 1$ and is often called a **black body**.
- Why the name black? Because it absorbes ALL incident light (or EM radiation).



Examples of Black Bodies

Nothing is exactly a black body, but some things are pretty close.

$e \approx 0.96$

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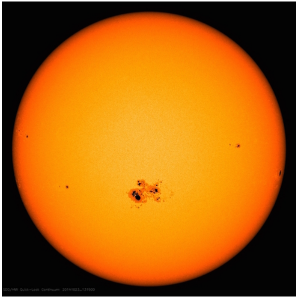
The **earth** is made mostly of these things and so the earth can also be considered a black body. The **sun** is also very close to being a black body

Check for Understanding - Sun Spots

Sun spots are cool places on the sun's surface that show up every 11 years. Even though they are cooler the total radiation from the sun increases when they are present. Let's model this assuming the sun takes up 10% of the sun's surface area. Let's also assume that the sunspots are 1000K cooler than the normal surface and that the rest of the surface heats up by 90K when the sun spots are present.



$$T_{\text{sun}} = 5800\text{K}$$
$$T_{\text{sun spot}} = 4800\text{K}$$
$$T_{\text{sun w/ spots}} = 5890\text{K}$$
$$e_{\text{sun}} = 0.965$$
$$A_{sun} = 5.10 \times 10^{14}\ \text{m}^2$$
$$\sigma = 5.6696 \times 10^{-8}\ \text{W/m}^2{\cdot}\text{K}^4$$

A. Calculate the output power of the sun without sun spots.

B. Calculate the output power of the sun WITH sun spots and compare to part A.

Reminder: $P = \sigma A e T^4$

Check for Understanding - Sun Spots

For part A:

$$
\begin{aligned}
P_{\mathrm{A}} &= \sigma A e T^4 \\
&= (5.6696 \times 10^{-8}\ \mathrm{W/m^2K^4})(5.10 \times 10^{14}\ \mathrm{m^2})(0.965)(5800\ \mathrm{K})^4 \\
&= 3.1576 \times 10^{22}
\end{aligned}
$$

For part B:

$$
\begin{aligned}
P_{\mathrm{B}} &= \sigma(0.1A)eT^4_{\text{sun spot}} + \sigma(0.9A)eT^4_{\text{sun w/ spots}} \\
&= (5.6696 \times 10^{-8}\ \mathrm{W/m^2K^4})(0.1 \cdot 5.10 \times 10^{14}\ \mathrm{m^2})(0.965)(4800\ \mathrm{K})^4 \\
&\quad + (5.6696 \times 10^{-8}\ \mathrm{W/m^2K^4})(0.9 \cdot 5.10 \times 10^{14}\ \mathrm{m^2})(0.965)(5890\ \mathrm{K})^4 \\
&= 3.1705 \times 10^{22}
\end{aligned}
$$

Check for Understanding - Project

Using these ideas of thermal transport (conduction, convection, and radiation) design with your group the most effective thermal inculating cup that you can think of.

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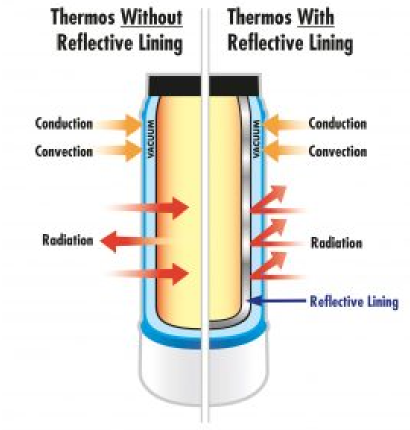

Check for Understanding - Warm Cloudy Nights

Explain why nights with cloud cover are warmer than nights with clear skies?

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Some of the earth's radiation gets reflected back down by the moisture in the clouds, just like the radiation trying to escape an insulated cup with a reflective coating.

Picture References

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