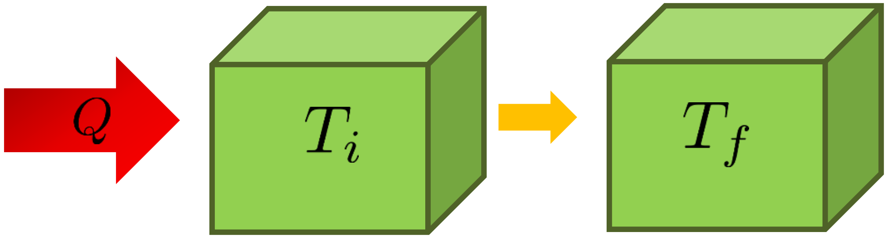
19-2: First Law & Specific Heats for Gases

Recall what we have for solids and liquids:

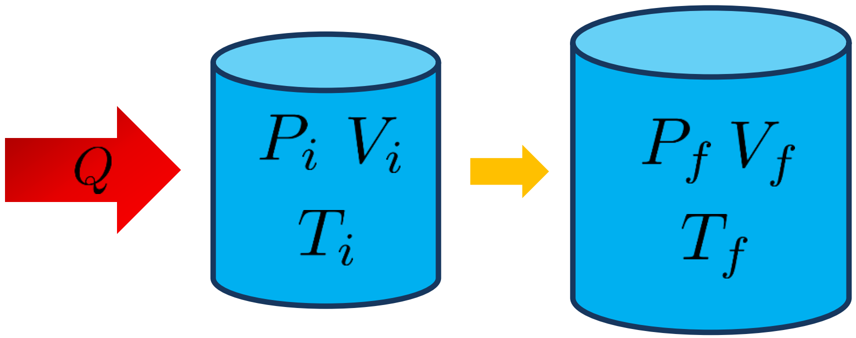


$$\Delta E_{\rm th} = Q + \cancel{W} = Mc\Delta T$$

$\cancel{W} \rightarrow$ **0**

So, all of the heat goes into raising the temperature – if there is no phase change.

Now, what about gases?



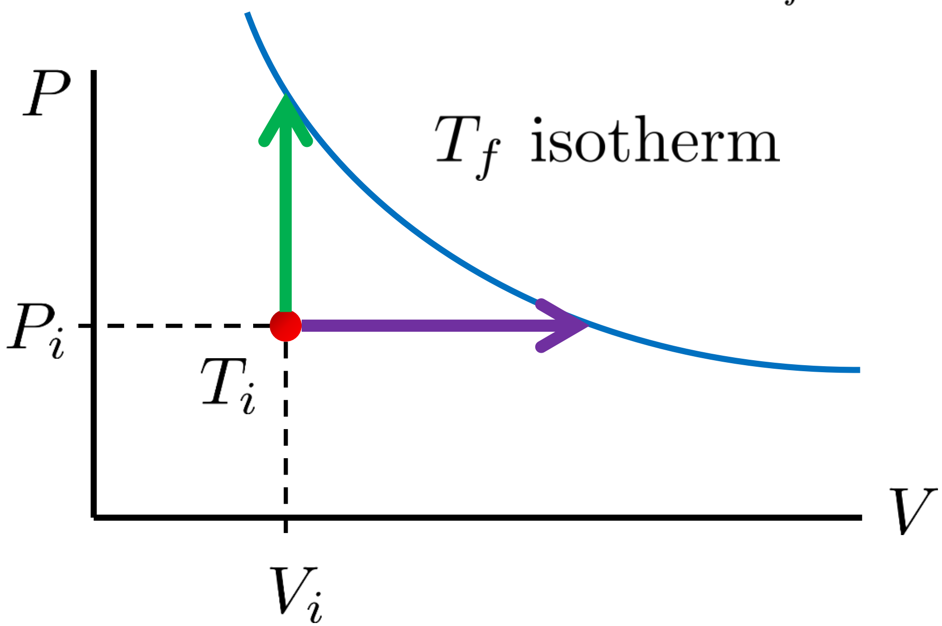
Here, P and V can change, so work can be done on or by the system.

So with a gas, for a given Q, what is $\Delta T = T_f - T_i$?

There is no single answer; it depends on the path between the initial state and the final state, i.e. how much work is done on or by the gas.

Specific Heats of Gases

Consider a gas at some initial state *i*. How much heat is required for a given temperature change? $\Delta T = T_f - T_i$



We can't really determine this since we can follow any path from point *i* to any point on the T_f isotherm.

Each path will have a different W, and hence a different Q.

So we define two special paths: Constant Volume and Constant Pressure.

For these two paths, we can **define two specific heats**:

$Q = nC_V \Delta T$ for a Constant Volume path

$Q = nC_P \Delta T$ for a Constant Pressure path

$C_V \equiv$ **Molar specific heat** for a Constant Volume path

$C_P \equiv$ **Molar specific heat** for a Constant Pressure path

Specific Heats of Gases: Some Important Stuff

The thermal energy is a **State Variable** that **depends only on the temperature**.

So the change in thermal energy is the same for any change in temperature.

i.e. ***the change in thermal energy depends only on the initial and final temperatures, and does not depend on the path.***

Now, apply this idea to a Constant Volume Path:

$$\Delta E_{\text{th}} = Q + \cancel{W} \quad = \quad nC_V \Delta T$$ **(by definition)**

$$0 \ (\Delta V = 0)$$

But the change in thermal energy doesn't depend on the path; therefore:

$$\Delta E_{\text{th}} = nC_V \Delta T \text{ (for } \underline{\textbf{any}} \text{ process)}$$

But, $Q = nC_V \Delta T$ **only** for a constant volume process

Your author also shows that for an ideal gas, the specific heats are related:

$$C_P = C_V + R$$

Whiteboard Problem: 19-5

A container holds 1.0 g of Argon at a pressure of 8.0 atm.

a) **How much heat is required to increase the temperature by 100°C at constant volume? (LC)**

b) **How much will the temperature increase if this amount of heat energy is transferred to the gas at constant pressure?(LC)**

Why do you get a different change in temperature for part b when you supplied the same amount of heat to the gas? Draw them both on a PV diagram.

TABLE 19.4 Molar specific heats of gases (J/mol K) at $T = 0°C$

Gas	C_P	C_V	$C_P - C_V$
Monatomic Gases			
He	20.8	12.5	8.3
Ne	20.8	12.5	8.3
Ar	20.8	12.5	8.3
Diatomic Gases			
H_2	28.7	20.4	8.3
N_2	29.1	20.8	8.3
O_2	29.2	20.9	8.3

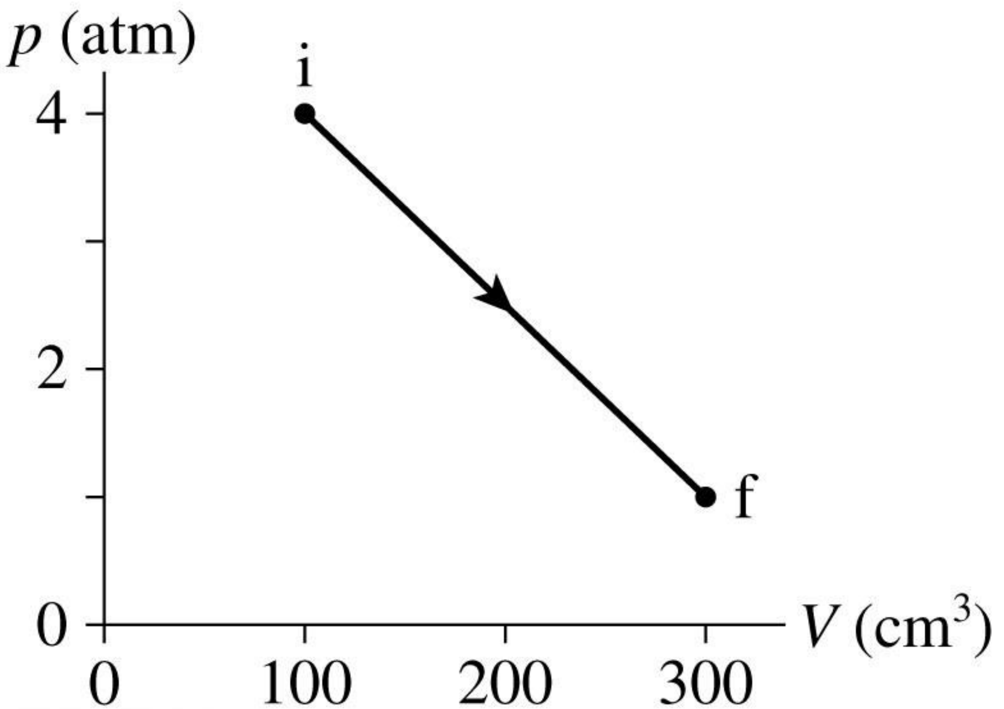
Whiteboard Problem: 19-6

(a really wonderful problem – a 2-point shot on LC)

The figure shows a thermodynamic process followed by 0.015 moles of diatomic hydrogen, H_2.

How much heat energy is transferred to the gas? (LC)

(how are you going to do this problem?)



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The Adiabatic Process

There are two **equally important** things to know about an adiabatic process:

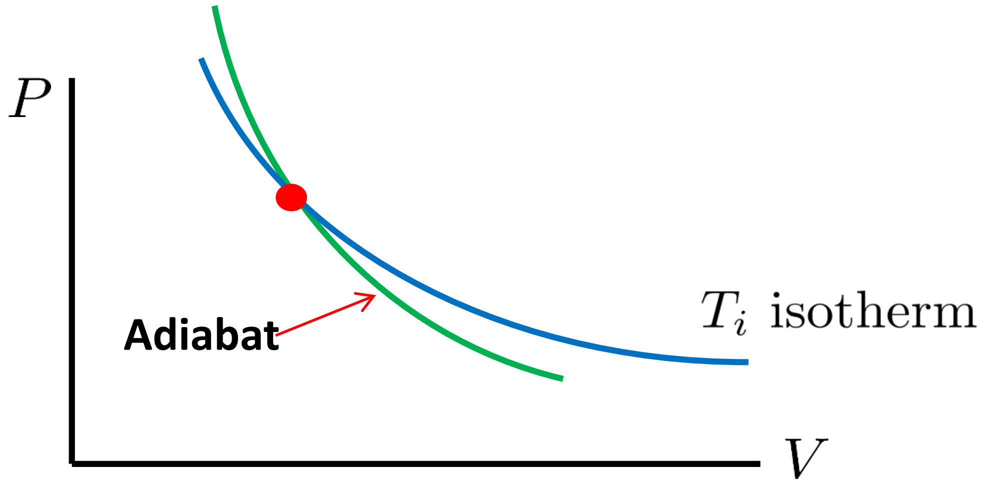
1.) **Q = 0 for an Adiabatic Process:** ***i.e. no Heat enters or leaves the system.***

2.) For an Adiabatic Process:

$$PV^{\gamma} = \text{constant} \quad \text{where: } \gamma = \frac{C_P}{C_V}$$

This defines the shape of an adiabatic process on a PV diagram: $P \propto \frac{1}{V^{\gamma}}$ and $\gamma = \frac{C_P}{C_V} \overset{\text{always}}{>} 1$

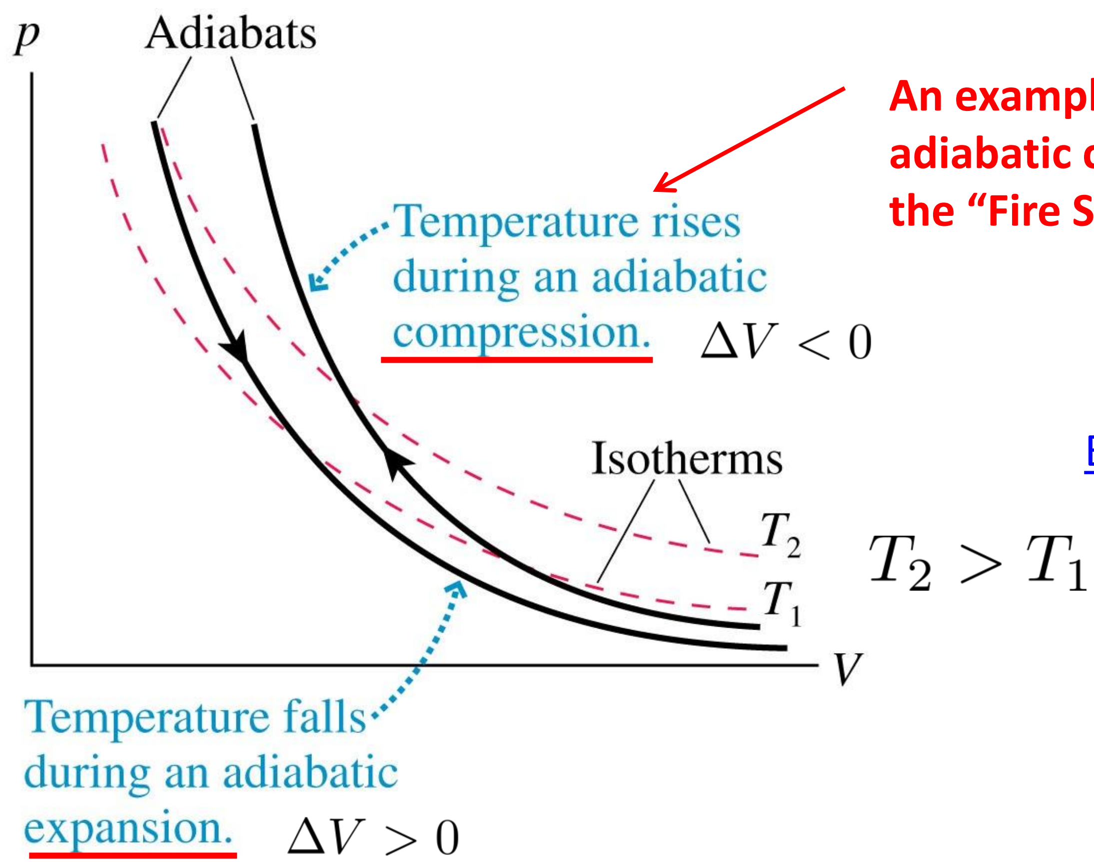
So, an adiabat is always steeper than an isotherm on a PV plot.



The Adiabatic Process

How can you make a process adiabatic?

- Thermally insulate the system
- Process is done very quickly – so there is no time for heat to be exchanged



An example of adiabatic compression, the "Fire Syringe"

Demo

Backup Video

Where have you experienced this?

Whiteboard Problem: 19-7

How hot does the fire syringe get? The tube of air is initially at a temperature of 20^{o}C and pressure of 1.0 atm. The air is confined to a cylinder of diameter 1.0 cm that is initially 13.0 cm in length. After pushing the plunger, the length of the cylinder of gas is 0.5 cm with no gas escaping.

(**For Air:** $\gamma = 1.4$)

Assuming that the process is adiabatic,

a) **What is the final pressure in atm? (LC)**
b) **What is the final temperature in ^{o}C? (LC)**

(there are three ways to do this part, one difficult, one so-so, and one really easy)

Heat Transfer Mechanisms

In this chapter, we've introduced the idea of heat as a transfer of energy due to a temperature difference.

However we haven't described how the transfer happens. In chapter 20, we'll look at a microscopic description of the process, but we can treat it macroscopically as well.

Engineering students (especially mechanical engineers) will likely take an entire course in Heat Transfer – MME403!

There are four ways that energy is transferred as heat between objects at different temperatures:

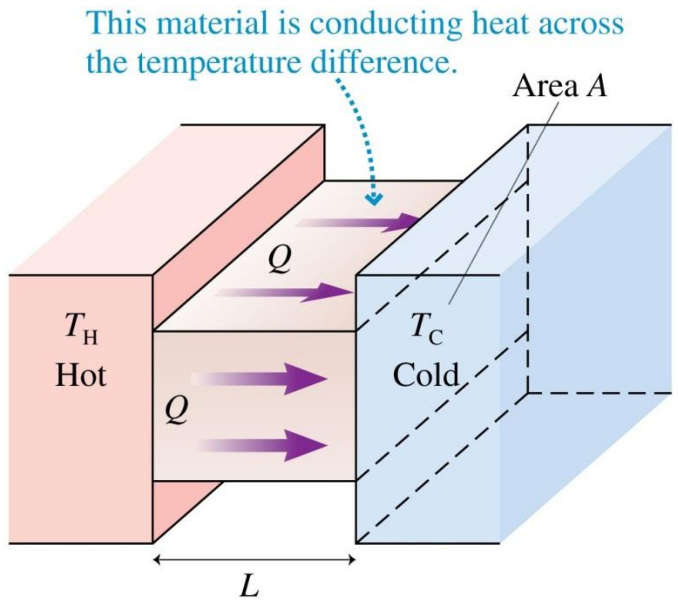
1. **Conduction**
2. **Convection**
3. **Radiation**
4. **Phase changes (e.g. evaporation)**

We've already talked about phase changes, and of the rest, we'll quantitatively treat only conduction and radiation.

Heat Conduction

When objects at different temperatures are connected by matter, the hot object loses heat which "flows" into the cold object – very much like a fluid flowing.

(But how? Is heat a real fluid? Why does it spontaneously only flow from hot to cold? We'll see a nice explanation of this in the video that will be part of your HW assignment.)



The rate (i.e. the energy/time) that energy flows is:

$$\frac{Q}{\Delta t} = k\frac{A}{L}\Delta T \quad \left[\text{Units} : \frac{J}{s} = \text{Watt}\right]$$

Where: k = thermal conductivity of the material conducting the energy

Note the dependence on geometry (just like water in a pipe): the larger the area and the shorter the distance, the more heat flow.

Also, the heat "flows" because of a temperature difference, and

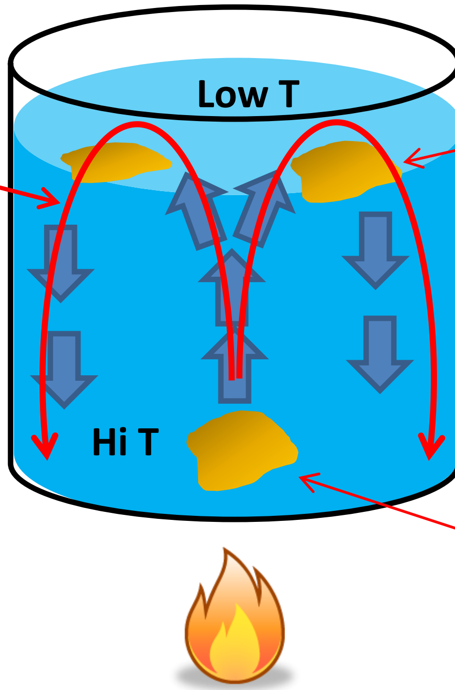
$$\frac{Q}{\Delta t} \propto \Delta T = T_H - T_C$$

This is why you can cool something more quickly by putting it in the freezer instead of the refrigerator.

Heat Transfer by Convection

Convection is the transfer of energy by the bulk motion of a fluid (gas or liquid) from a region of high temperature to a region of low temperature.

Sets up convection currents like in a boiling pot of water.



At the top, the piece of fluid cools, contracts, and falls.

A piece of the fluid heats, expands, rises.

Convection like this only happens in a fluid in a gravitational field.

Convection is a very difficult topic to treat theoretically since it is closely tied to the motion of the fluid which may be turbulent. We won't cover it here (*but, you mechanical engineers will likely learn how to deal with it!*)

Whiteboard Problem: 19-8

The ends of a 20 cm long, 2.0 cm diameter rod are maintained at 0°C and 100°C by immersion in an ice-water bath and boiling water. Heat is conducted through the rod at 4.5×10^4 J per hour. **Of what material is the rod made? (LC)**

Some Thermal Conductivities:

Water	**0.58**
Vacuum	**0.0**

What could you do with a material that has a very low thermal conductivity and a very high melting temperature?

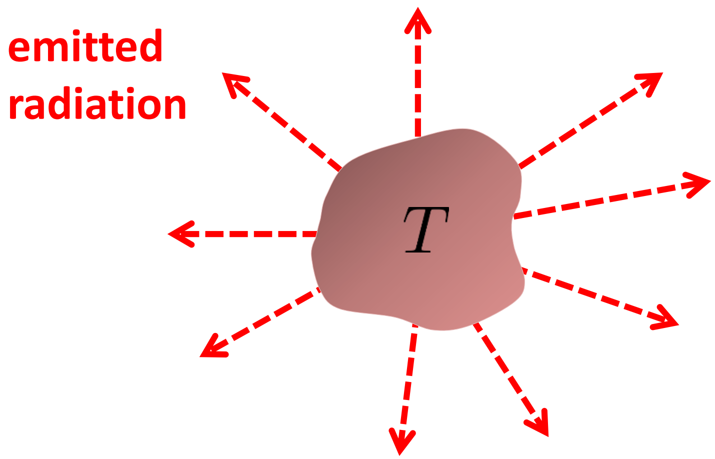
Demo

TABLE 19.5 Thermal conductivities

Material	k (W/m K)
Diamond	2000
Silver	430
Copper	400
Aluminum	240
Iron	80
Stainless steel	14
Ice	1.7
Concrete	0.8
Glass	0.8
Styrofoam	0.035
Air (20°C, 1 atm)	0.023

Heat Transfer by Radiation

All objects (at nonzero temperature) emit electromagnetic radiation called thermal radiation. The radiation carries energy away from the object, so it cools.



Emitted Power*:

$$\frac{Q_{\text{emit}}}{\Delta t} = e\sigma A T^4$$

where:

$A =$ surface area of the object

$\sigma = 5.67 \times 10^{-8} \frac{W}{m^2\ K^4}$ (Stefan-Boltzmann constant)

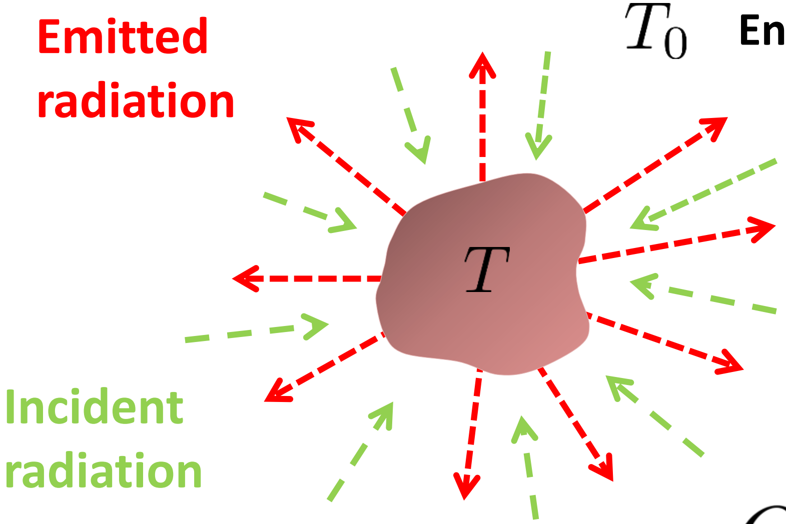
$e =$ emissivity; $0 \leq e \leq 1$ (property of the material, e = 1 for a blackbody)

$T =$ temperature **in Kelvin**

**This should look somewhat familiar; this is the Stefan Boltzmann Law for blackbody radiation (e = 1) that we looked at near the end of PHY181.*

Heat Transfer by Radiation

The object will also absorb radiation from the environment that is incident on it:



T_0 **Environment temperature**

Absorbed Power:

$$\frac{Q_{\mathrm{abs}}}{\Delta t} = e\sigma A T_0^4$$

The net power emitted is:

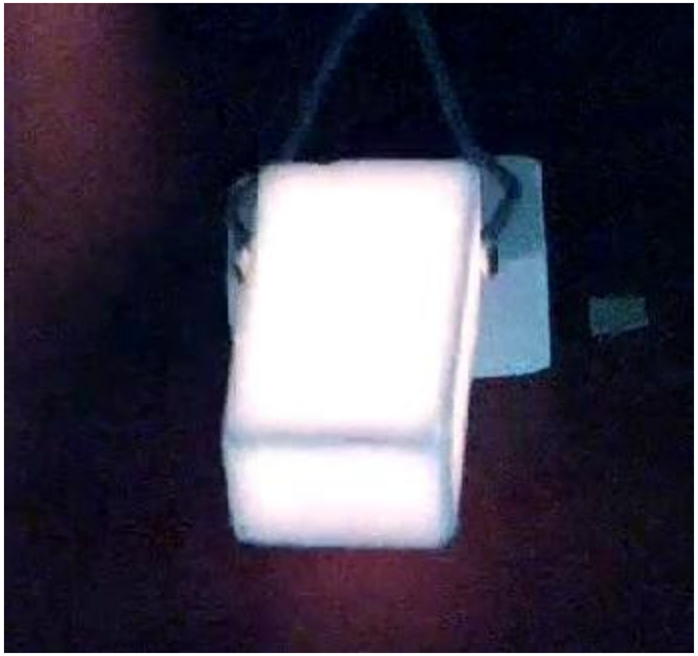
$$\frac{Q_{\mathrm{net}}}{\Delta t} = \frac{Q_{\mathrm{emit}}}{\Delta t} - \frac{Q_{\mathrm{abs}}}{\Delta t}$$

So:

$$\frac{Q_{\mathrm{net}}}{\Delta t} = e\sigma A(T^4 - T_0^4)$$

Whiteboard Problem: 19-9

The **Space Shuttle Tile** came out of the oven at 1100°C.
The sides of the rectangular tile measure to be 13.5 X 7.5 X 5.0 cm.
Determine the net rate of power radiated by the tile just as it was removed from the oven. (LC)
Assume that the emissivity, e, of the tile is 1.0 and the temperature of the environment is room temperature, 20°C.



$$\frac{Q_{\text{net}}}{\Delta t} = e\sigma A(T^4 - T_0^4)$$

Is the radiation power that you calculated, emitted in the visible part of the spectrum?

Some, but not all of it, most of the power is in the infrared which we can't see but we can feel. Remember the Black Body Spectrum?

Note about Whiteboard Problem: 19-10

- We didn't get to do WB 19-10 in class. We'll leave in the lecture packet and post the solution of the Calendar page. Make sure that you know how to do it.

- Also, you may want to play with PhET Greenhouse Effect simulation.

- The one that we used in class that shows photons is at:

https://phet.colorado.edu/en/simulations/greenhouse-effect

Just hold Ctrl and click on the link. I like the version with photons.

Whiteboard Problem: 19-10

The Sun's intensity at the distance of the Earth is I_s =1370 W/m^2. Due to blockage by clouds, only ~70% of this intensity typically gets to the surface and is absorbed.

What is the Earth's average temperature in °C? (LC)

The emissivity of the Earth's surface is very close to 1.

Hint: The surface of the Earth absorbs solar radiation that has an intensity at the surface of $(0.7)I_s$. The Earth also emits radiation since it has a temperature T (take the emissivity to be 1).
Don't use the equation on slide # 14; instead, at equilibrium, impose:

absorbed power = the emitted power

(remember, power = intensity X area)

Set this condition up and solve for the temperature of the Earth.
(no, you really don't need to know the radius of the Earth, but look it up if you want to use it.)

The equilibrium temperature that you should be getting for the Earth is less than the freezing point of water. The actual average temperature of the Earth is about 15 - 20°C higher due to the Greenhouse Effect.
How does the Greenhouse Effect raise the Earths' temperature?

PhET GHE