Course announcement

- The solution of the second midterm has been posted on eLearn.
- We will have one more homework set for this course, which will be announced on 12/27(Tue.) and due on 1/3(Tue.).

GENERAL PHYSICS B1
TEMPERATURE AND HEAT

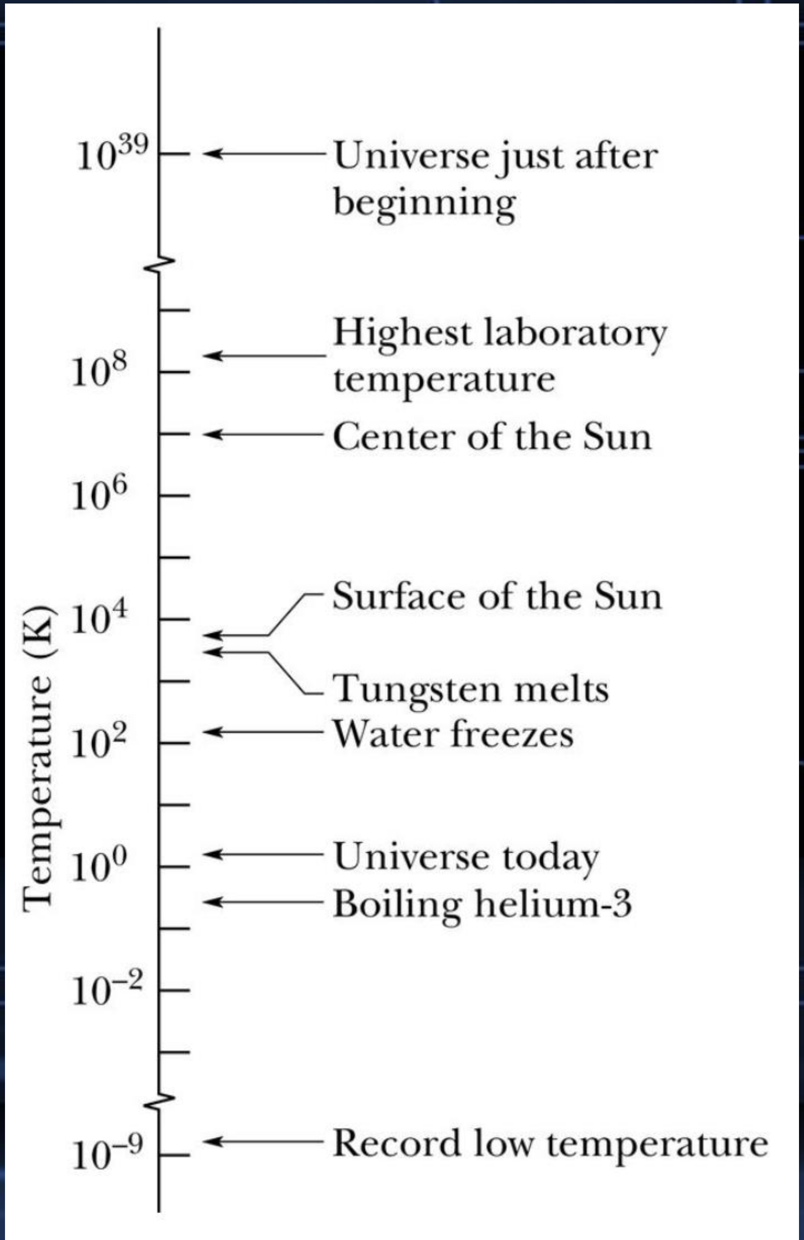
2022/12/13

Heat capacity, specific heat, and heat transfer

13	12/9(Fri.)	**Temperature and Heat:** temperature, heat and thermal equilibrium
14	12/13(Tue.)	**Temperature and Heat:** Heat capacity, specific heat, and heat transfer
14	12/16(Fri.)	**Thermal Behavior of Matter:** ideal gases, and kinetic theory of ideal gas
15	12/20(Tue.)	**Thermal Behavior of Matter:** phase changes and thermal expansion

Temperature

- Temperature is one of the seven SI base quantities. Physicists measure temperature on the Kelvin scale, which is marked in units called kelvins.
- The temperature of a natural system apparently has no upper limit, it does have a lower limit; this limiting low temperature is taken as the zero of the Kelvin temperature scale.



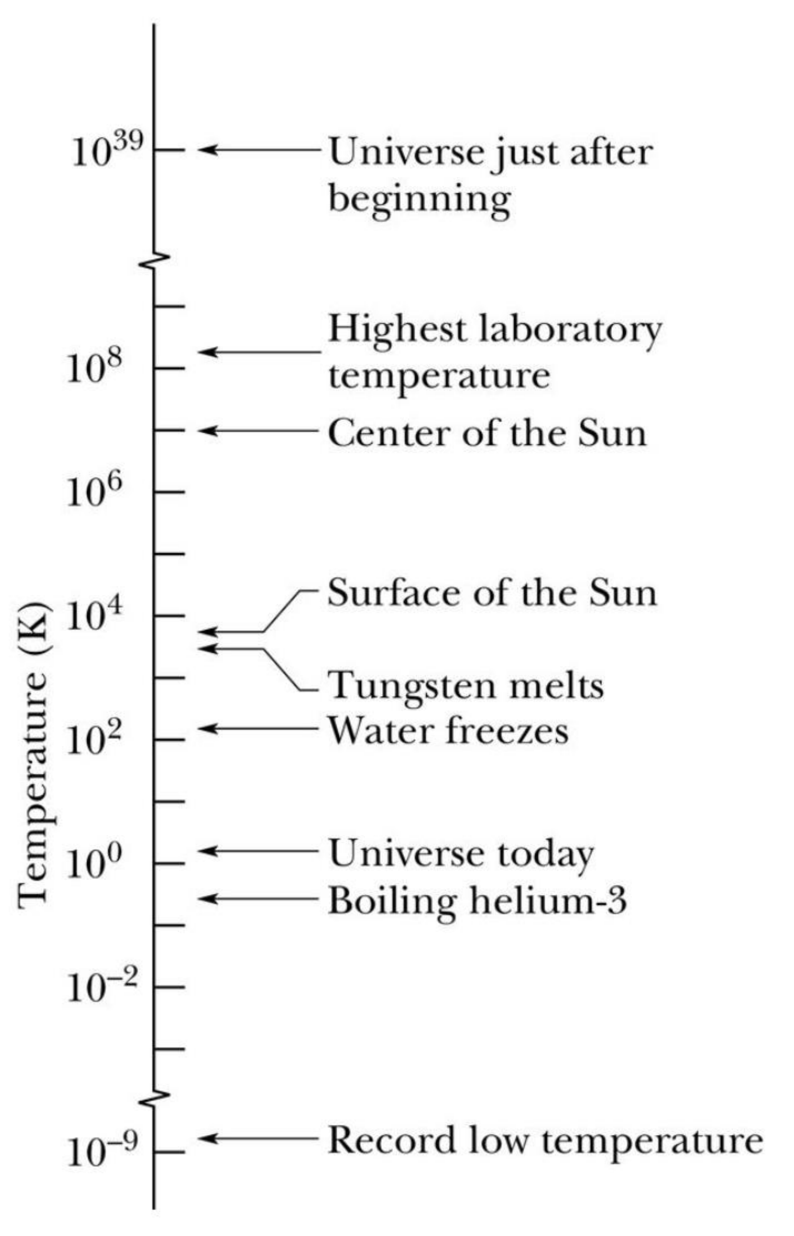
Temperature

- A first look of the meaning of temperature is associated with how much energy containing in the system.

System with

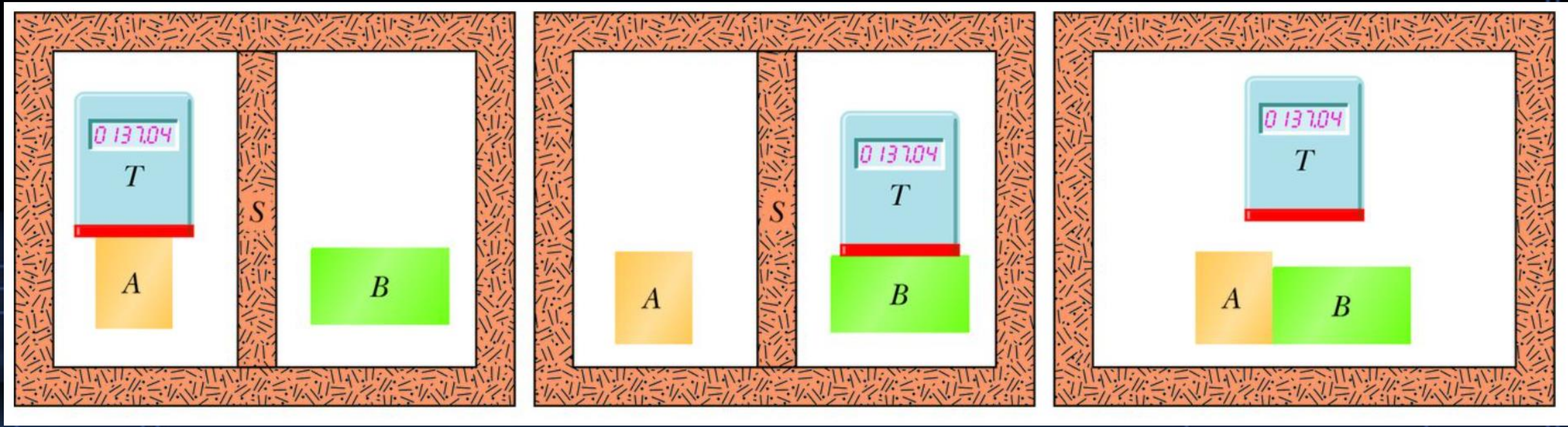
high energy: high temperature

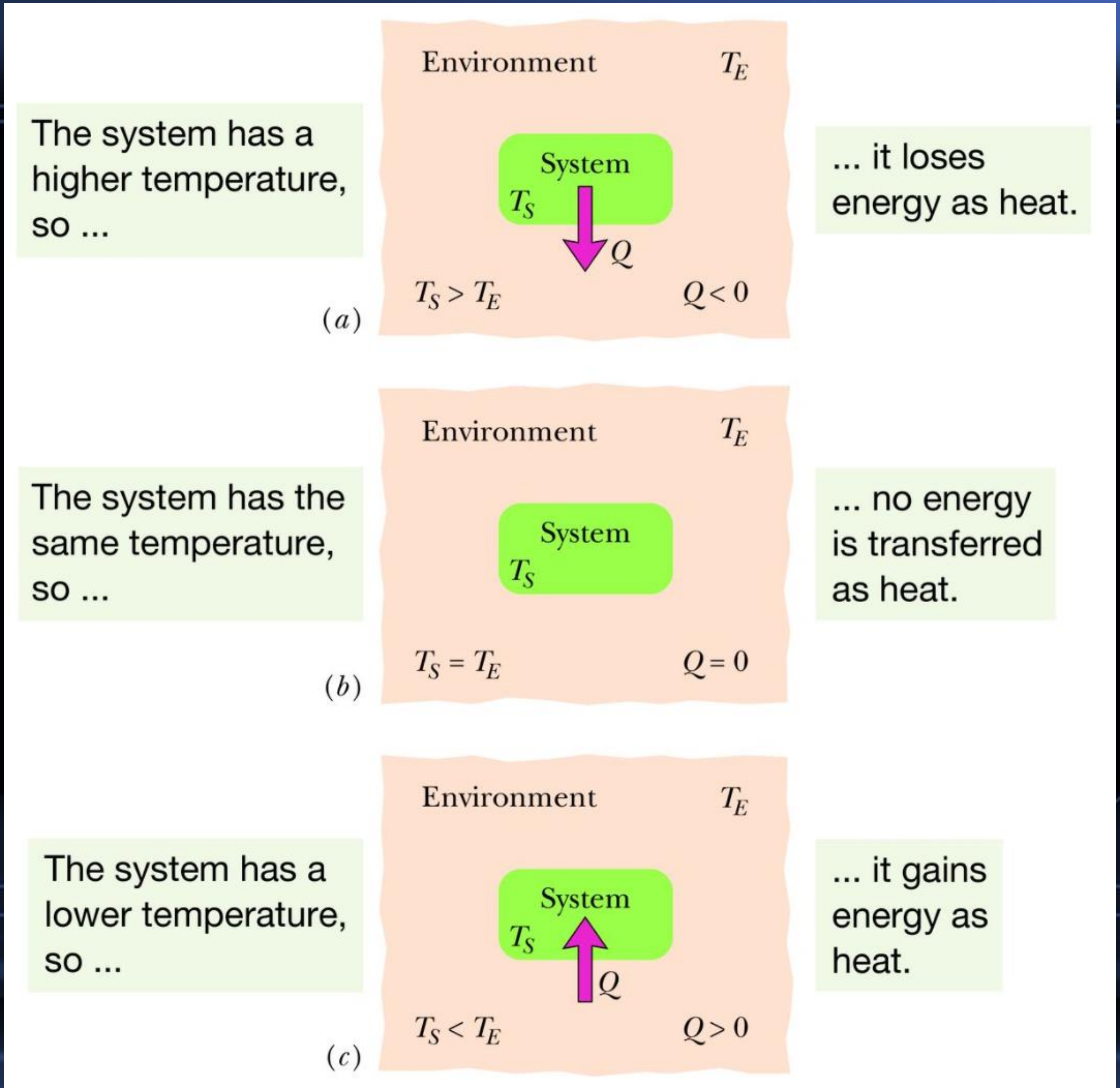
Low energy: low temperature



The Zeroth Law of Thermodynamics

- If bodies A and B are each in thermal equilibrium with a third body T, then A and B are in thermal equilibrium with each other.




Environment
T_E
The system has a higher temperature, so ...
System
T_S
Q
$T_S > T_E$
$Q < 0$
(a)
... it loses energy as heat.
Environment
T_E
The system has the same temperature, so ...
System
T_S
$T_S = T_E$
$Q = 0$
(b)
... no energy is transferred as heat.
Environment
T_E
The system has a lower temperature, so ...
System
T_S
Q
$T_S < T_E$
$Q > 0$
(c)
... it gains energy as heat.

Heat

- Heat is the energy transferred between a system and its environment because of a temperature difference that exists between them.
- Before scientists realized that heat is transferred energy, heat was measured in terms of its ability to raise the temperature of water. Thus, the calorie (cal) was defined as the amount of heat that would raise the temperature of 1 g of water from 14.5°C to 15.5°C.
- In 1948, the scientific community decided that since heat (like work) is transferred energy, the SI unit for heat should be the one we use for energy—namely, the joule. 1cal = 4.1868J

Today’s topics

- Heat capacity and specific heat
- Heat transfer
- Thermal-energy balance

The Absorption of Heat by Solids and Liquids

- The heat capacity C of an object is the proportionality constant between the heat Q that the object absorbs or loses and the resulting temperature change ΔT of the object:

$$Q = C\,\Delta T = C(T_f - T_i)$$

- Specific Heat: A “heat capacity per unit mass” or specific heat c that refers not to an object but to a unit mass of the material of which the object is made.

$$Q = cm\,\Delta T = cm(T_f - T_i)$$

Substance	Specific Heat, c SI Units: J/kg·K	Specific Heat, c cal/g·°C, kcal/kg·°C, or Btu/lb·°F
Aluminum	900	0.215
Concrete (varies with mix)	880	0.21
Copper	386	0.0923
Iron	447	0.107
Glass	753	0.18
Mercury	140	0.033
Steel	502	0.12
Stone (granite)	840	0.20
Water:		
Liquid	4184	1.00
Ice, −10°C	2050	0.49
Wood	1400	0.33

*Temperature range 0°C to 100°C except as noted.

Example: Waiting to Shower

- Your whole family has showered before you. Dropping the temperature in the water heater to 18°C. If the heater holds 150kg of water, how much energy will it take to bring it up to 50°C? If the energy is supplied by a 5.0kW electric heating element, how long will that take?

Example: Waiting to Shower

- The total required heat to let 150kg water temperature rise to 50°C from 18°C is:

$$Q = mc\Delta T = (150kg)\cdot(4184J/kg\cdot K)\cdot(50^{\circ}\mathrm{C} - 18^{\circ}\mathrm{C})$$

$$= 20MJ$$

- The total time to heat up all the water is:

$$\Delta t = \frac{Q}{P} = \frac{2.0\times10^{7}J}{5.0\times10^{3}J/s} = 4000s$$

The Equilibrium Temperature

- When objects at different temperatures are in thermal contact, heat flows from the hotter object to the cooler on until they reach thermodynamic equilibrium. Assuming the objects are thermally insulated from surroundings, then:

$$m_1 c_1 \Delta T_1 + m_2 c_2 \Delta T_2 = 0$$

Which is a form of conservation of energy

Example: Cooling down

- An aluminum frying pan of mass 1.5kg is at 180°C when it's plunged into a sink containing 8.0kg of water at 20°C. Assuming that non of the water boils and that no heat is lost to the surroundings, find the equilibrium temperature of the water and pan. $c_p = 900\left(\frac{J}{kgK}\right), c_w = 4184\left(\frac{J}{kgK}\right)$

Example: Cooling down

- An aluminum frying pan of mass 1.5kg is at 180°C when it's plunged into a sink containing 8.0kg of water at 20°C. Assuming that non of the water boils and that no heat is lost to the surroundings, find the equilibrium temperature of the water and pan. $c_p = 900\left(\frac{J}{kgK}\right), c_w = 4184\left(\frac{J}{kgK}\right)$

Assuming the final temperature is T, we have:

$$m_p c_p (T - T_p) + m_w c_w (T - T_w) = 0$$

Plugging the given numbers we can get T= 26°C

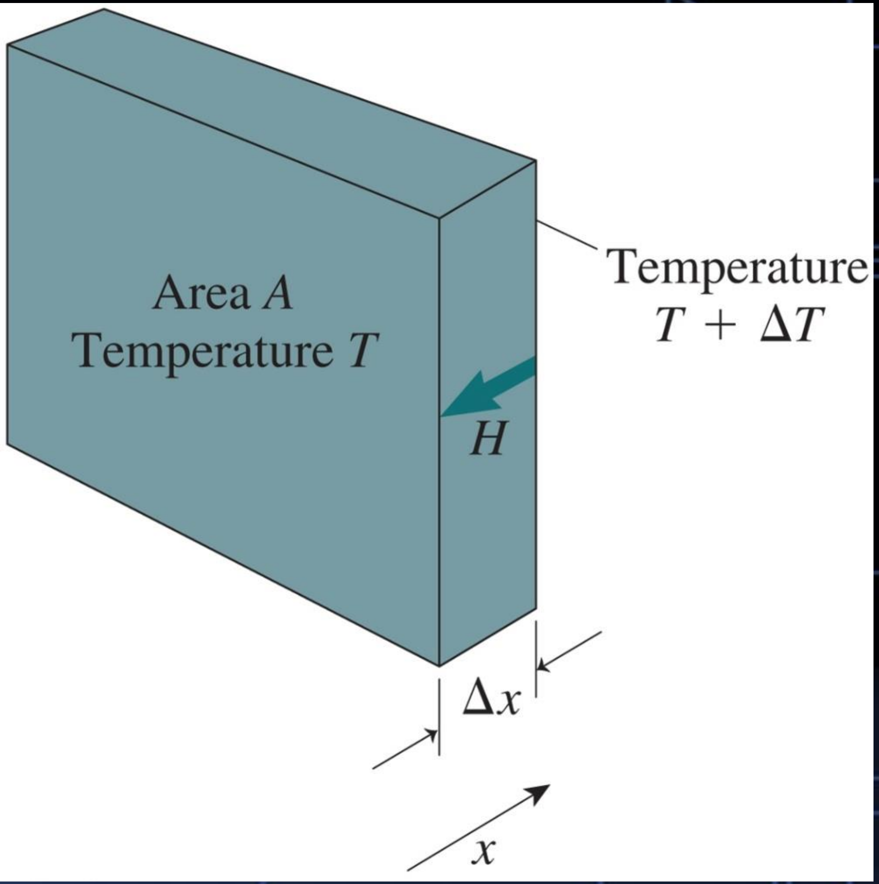
Heat Transfer Mechanisms

- We have discussed the transfer of energy as heat between a system and its environment, but we have not yet described how that transfer takes place. There are three transfer mechanisms: conduction, convection, and radiation.

Conduction

- Consider a slab of face area A and thickness L, whose faces are maintained at temperatures T and T+ΔT, Experiment shows that the heat conduction rate H (the amount of heat Q transferred per unit time t) is:

$$H = \frac{dQ}{dt} = -kA\frac{\Delta T}{\Delta x}$$



Where k is the thermal conductivity with SI unit of W/mK

Thermal Conductivity

Table 16.2 Thermal Conductivities*

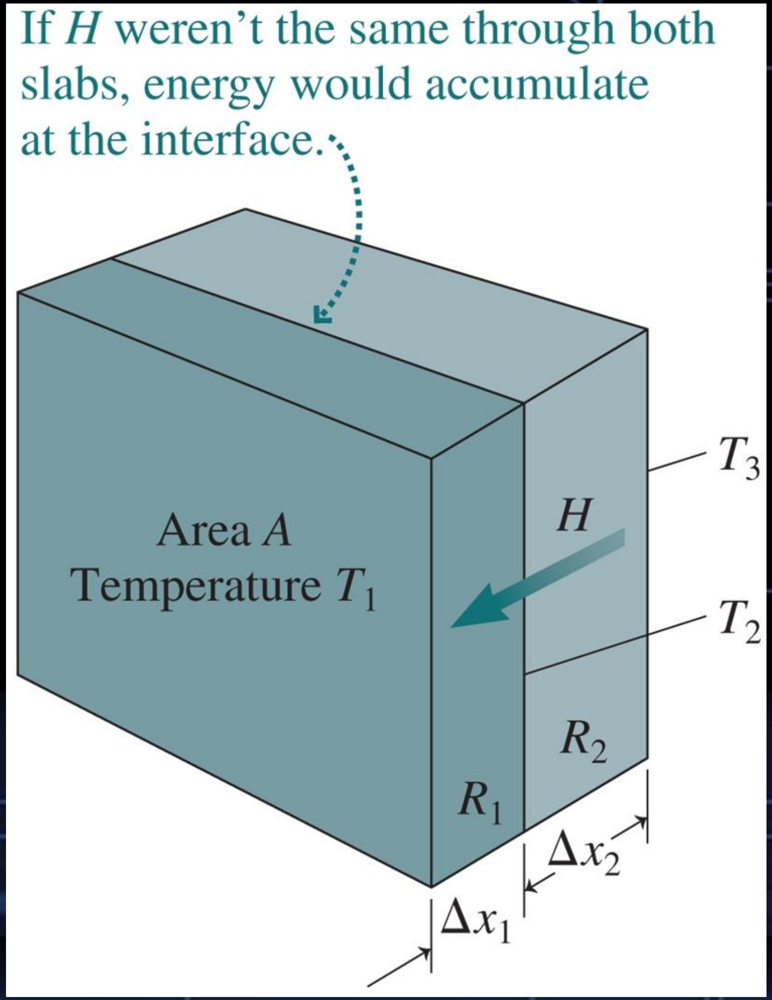
Material	Thermal Conductivity, *k*: SI Units: W/m·K	Thermal Conductivity, *k*: British Units: Btu·in/h·ft^2·°F
Air	0.026	0.18
Aluminum	237	1644
Concrete (varies with mix)	1	7
Copper	401	2780
Fiberglass	0.042	0.29
Glass	0.7–0.9	5–6
Goose down	0.043	0.30
Helium	0.14	0.97
Iron	80.4	558
Steel	46	319
Styrofoam	0.029	0.20
Water	0.61	4.2
Wood (pine)	0.11	0.78

*Temperature range 0°C to 100°C.

Conduction of a composite slab

- If we consider a composite slab as shown in the figure that contains two different materials with thermal conductivity k_1 and k_2.
- The heat flow H must be the same through both slabs, so energy doesn't accumulate at the interface:

$$H = -k_1 A \frac{T_2 - T_1}{\Delta x_1} = -k_2 A \frac{T_3 - T_2}{\Delta x_2}$$



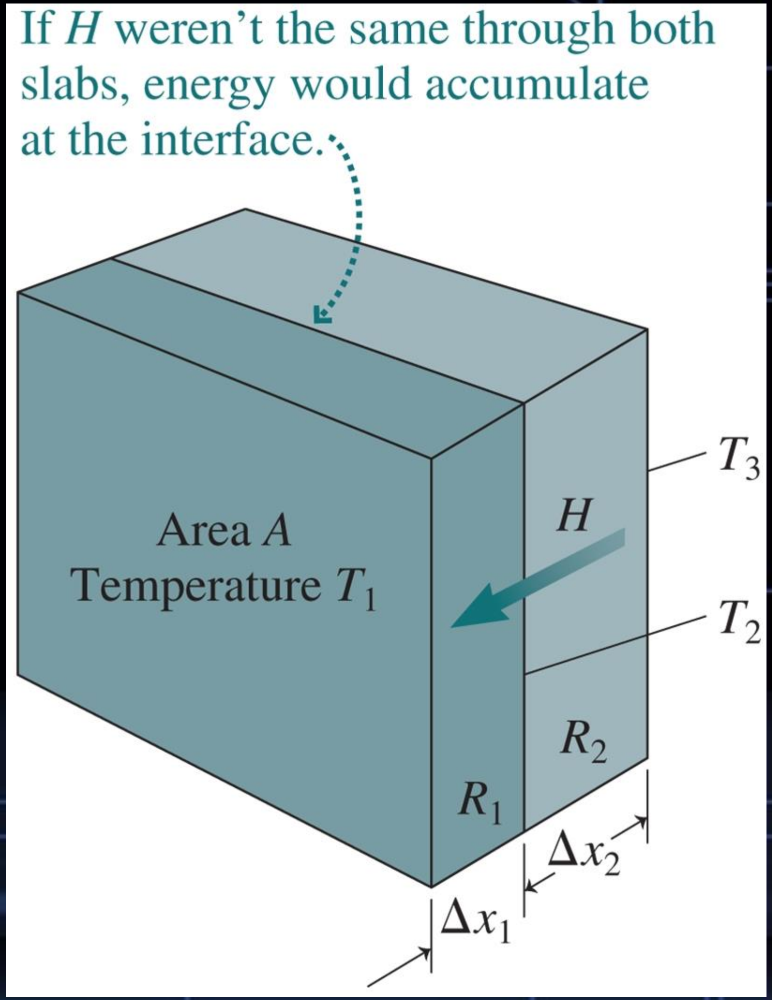
Conduction of a composite slab

- We can define the thermal resistance R of each slab as:

$$R = \frac{\Delta x}{kA}$$

- One can find out that the heat flow H is

$$H = \frac{T_1 - T_3}{R_1 + R_2}$$

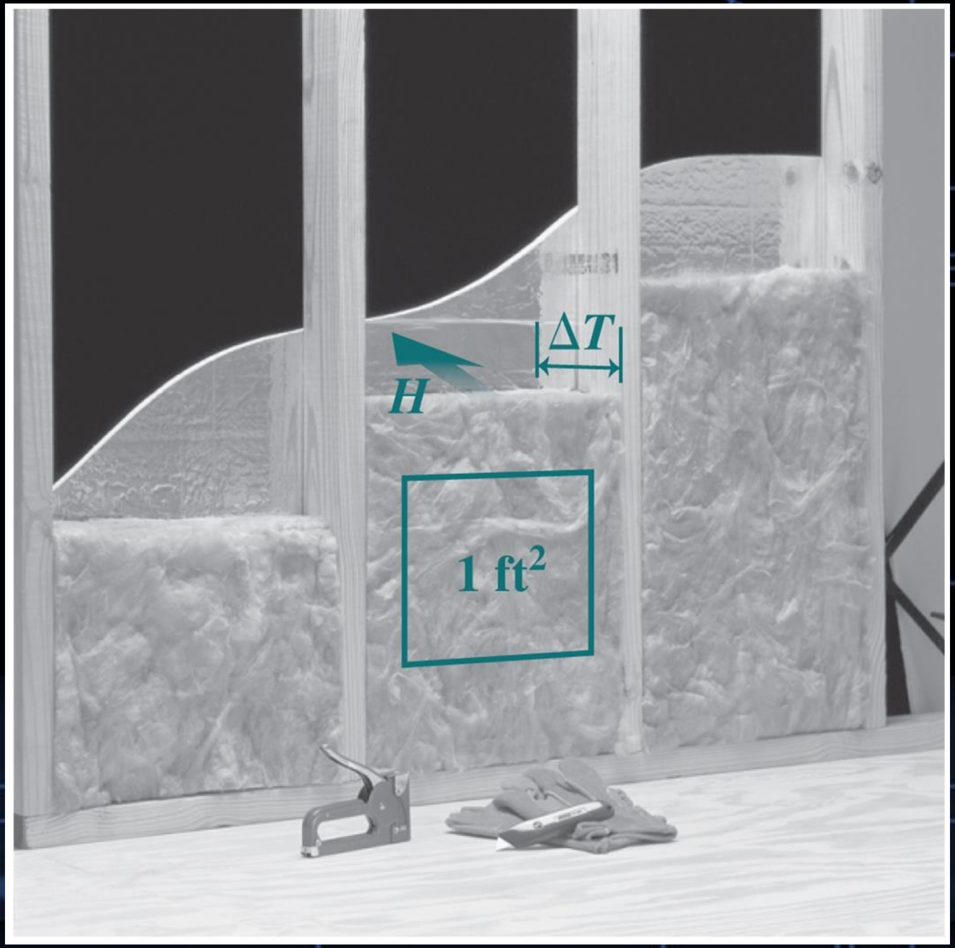


$\mathcal{R}$ factor

- Insulating properties of building materials are described by the $\mathcal{R}$ -factor, which is the thermal resistance for a slab of unit area:

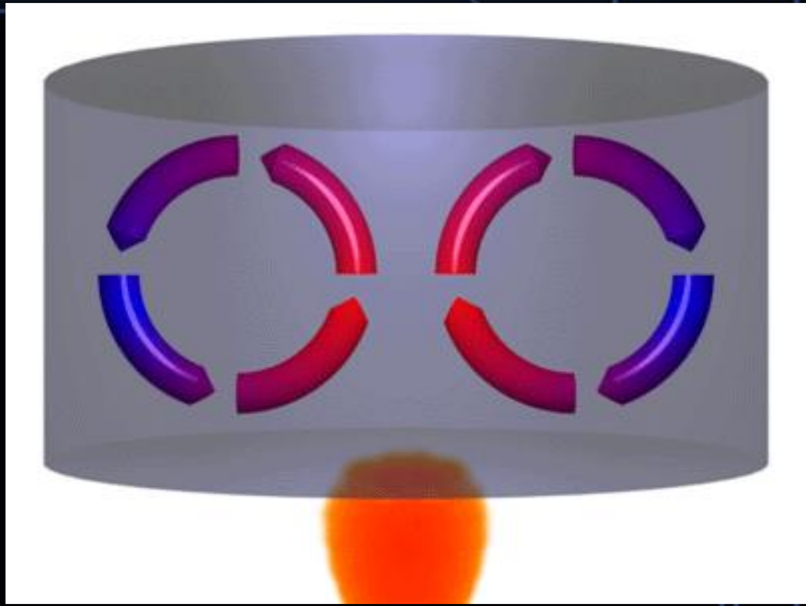
$$\mathcal{R} = RA = \frac{\Delta x}{k}$$

With SI unit of m^2K/W. In the united states, the unit is $ft^{2\circ}Fh/Btu$.

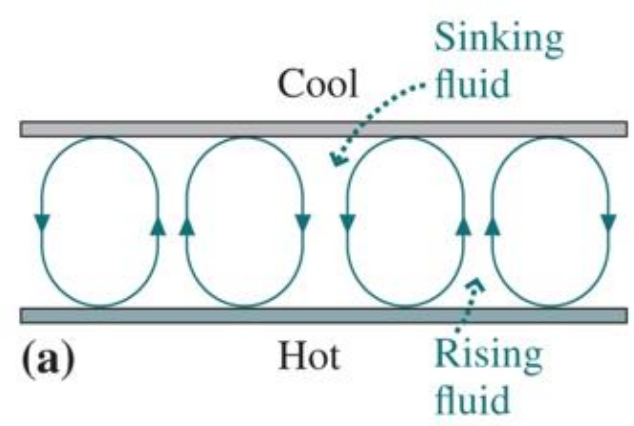


Convection

- Convection: The energy transfer occurs with a fluid motion. When a fluid, such as air or water, comes in contact with an object whose temperature is higher than that of the fluid, heat can be transferred due to fluid flow



https://commons.wikimedia.org/wiki/File:Convection.gif



Radiation

- The third method by which an object and its environment can exchange energy as heat is via electromagnetic waves. Energy transferred in this way is often called thermal radiation.
- The rate P at which an object emits energy via electromagnetic radiation depends on the object's surface area A and the temperature T of that area in kelvins and is given by

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

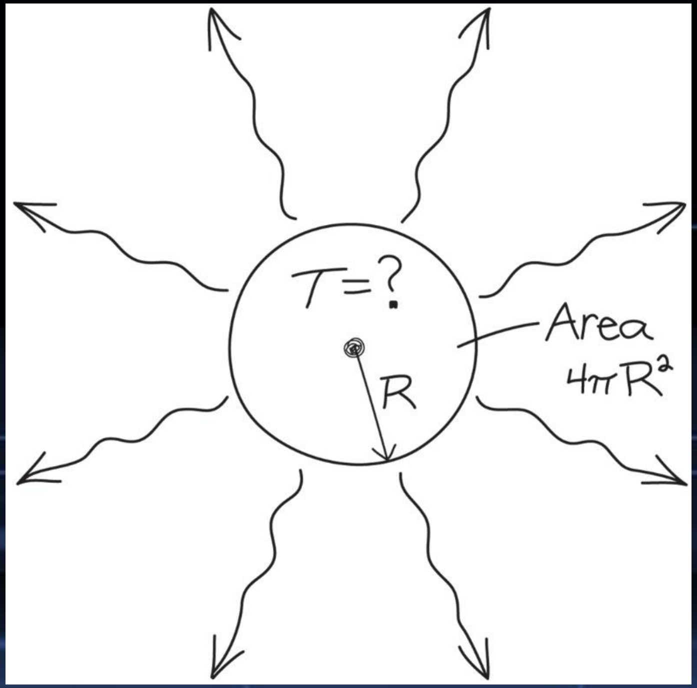
Radiation

$$P = e\sigma AT^4$$

Here σ is named after Josef Stefan (who discovered experimentally in 1879) and Ludwig Boltzmann (who derived it theoretically soon after). The symbol e represents the emissivity of the object's surface, which has a value between 0 and 1.

Example: The Sun's temperature

- The sun radiates energy at the rate $P=3.83x10^{26}$W. And its radius is $r=6.96x10^{8}$ m. Treating the Sun as a black body (e=1), find its surface temperature.

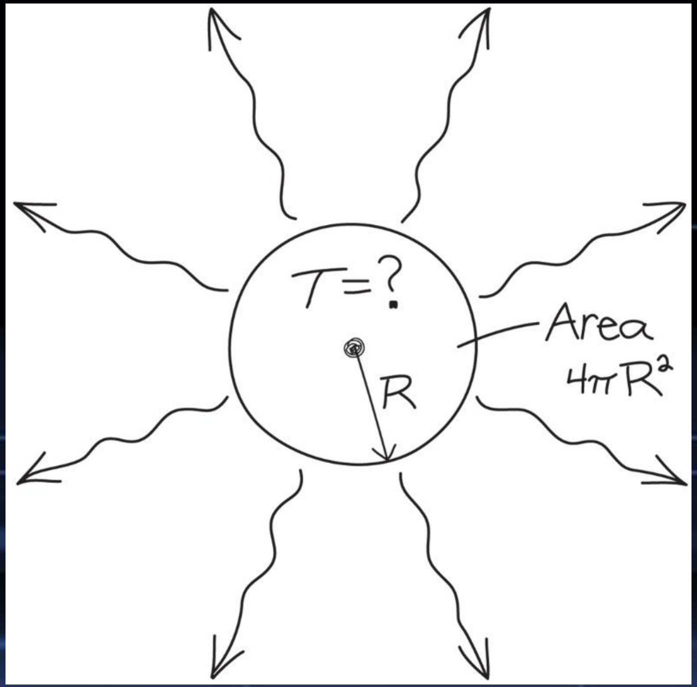


Example: The Sun's temperature

- The sun radiates energy at the rate $P=3.83x10^{26}$W. And its radius is $r=6.96x10^{8}$ m. Treating the Sun as a black body (e=1), find its surface temperature.

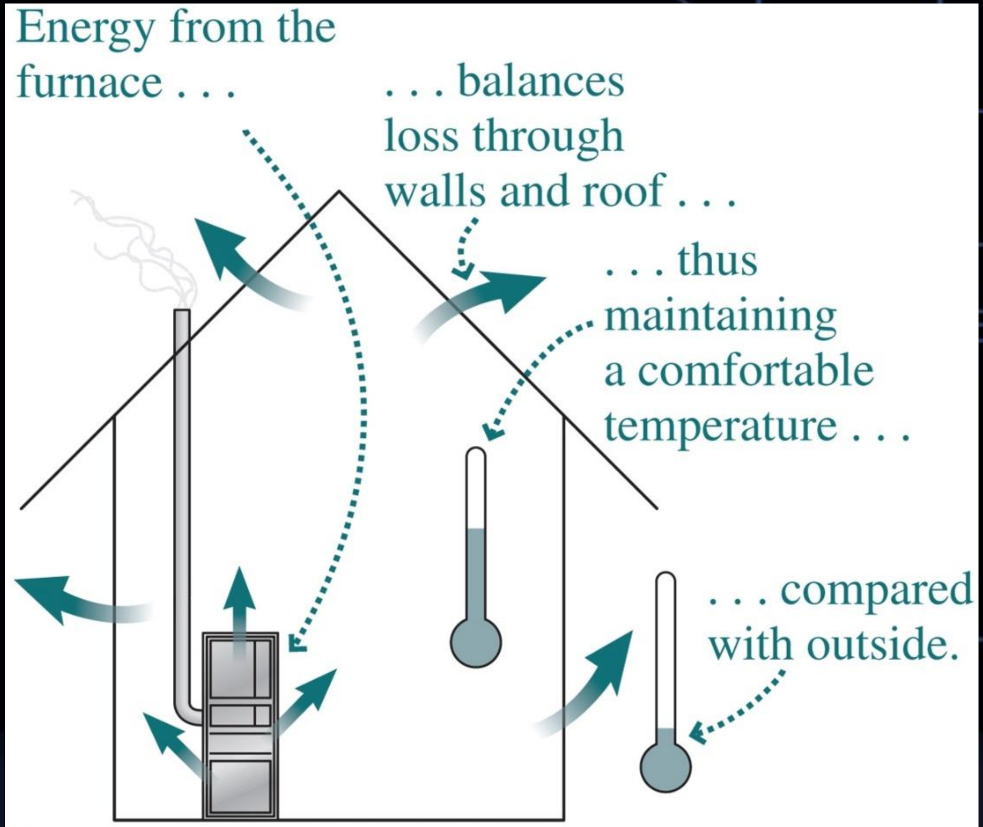
Base on Stefan-Boltzmann law the temperature is

$$T = \left(\frac{P}{4\pi R^2 \sigma}\right) = 5770K$$



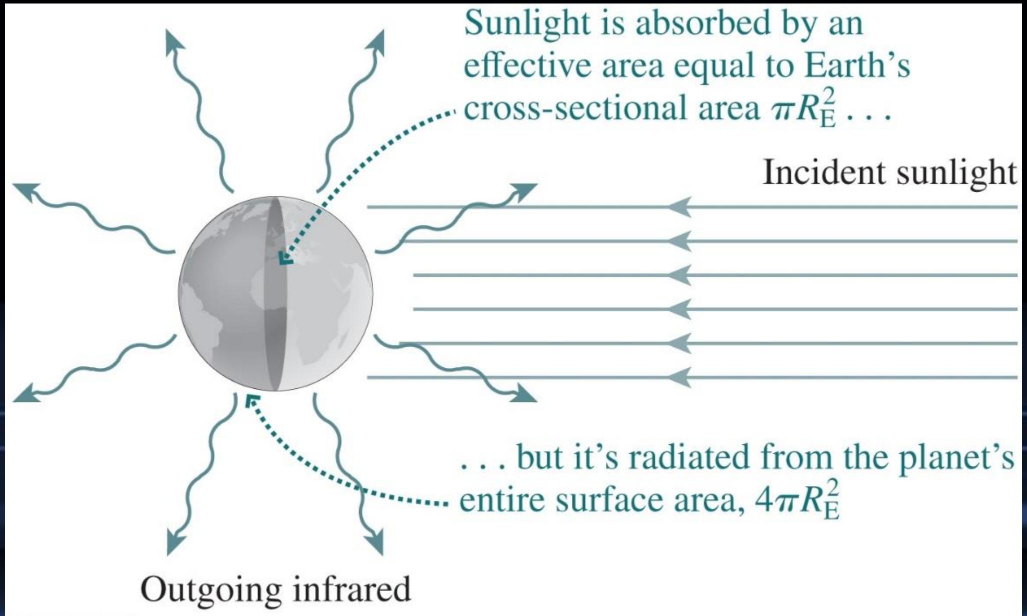
Thermal energy balance

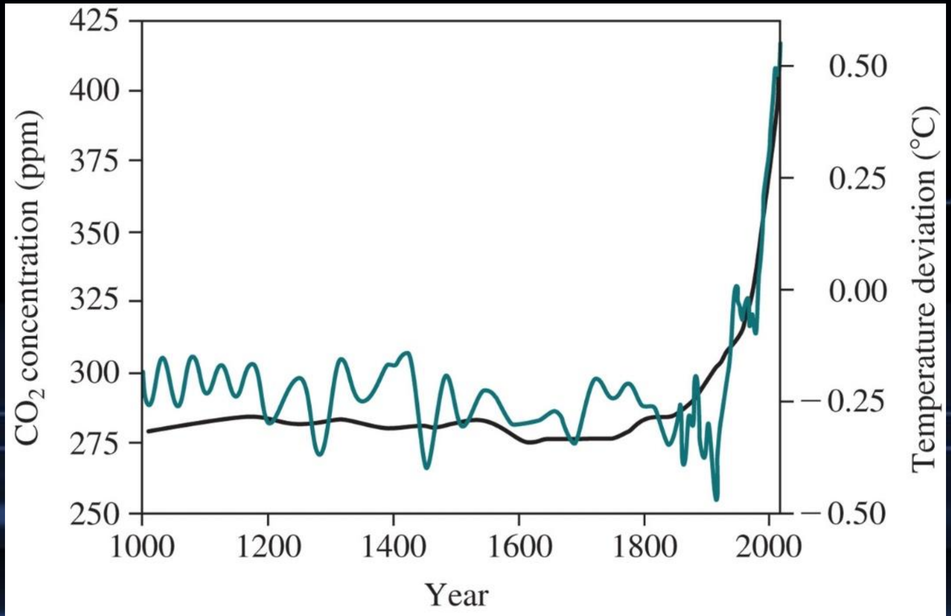
- You keep your house at a comfortable temperature in winter by balancing heat loss with energy from your heating system. This state of thermal-energy balance occurs throughout science and engineering.
- Energy balance: A system experiencing both energy input and energy loss comes to energy balance at the temperature for which the energy-loss rate equals the rate of energy input



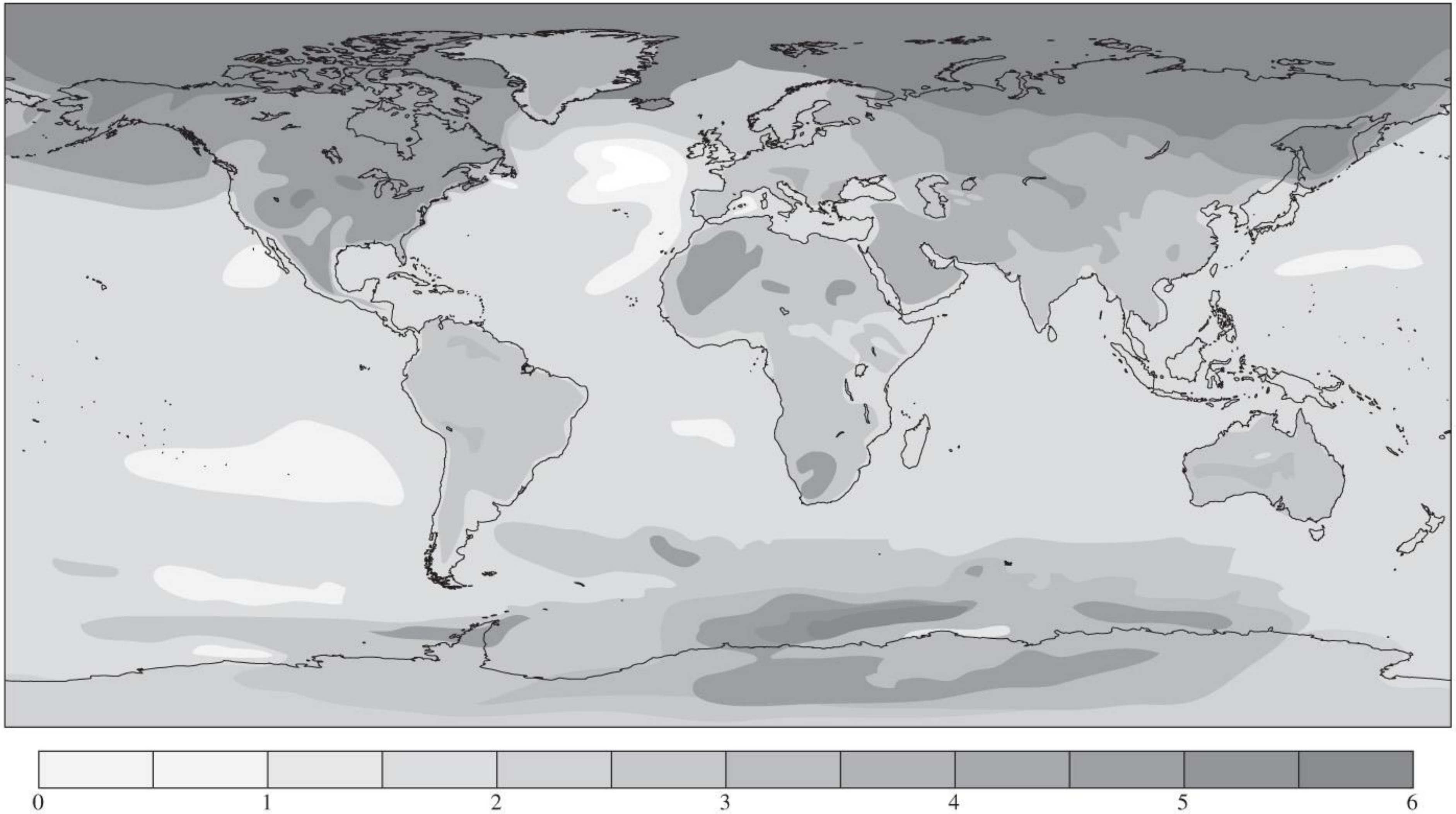
Greenhouse Effect and Global Warming

- The green house gases: Let sunlight pass through but impede outgoing infrared. This makes the surface temperature of the earth higher to get the same radiation to space.





Prediction of temperature change



Projected temperature change (°C), 2081–2100 versus 1986–2000