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Applied Natural Sciences

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Technische Universiteit **Eindhoven** University of Technology

Where innovation starts

Chapter 17

Temperature and Heat

PowerPoint® Lectures for
University Physics, Thirteenth Edition
– Hugh D. Young and Roger A. Freedman

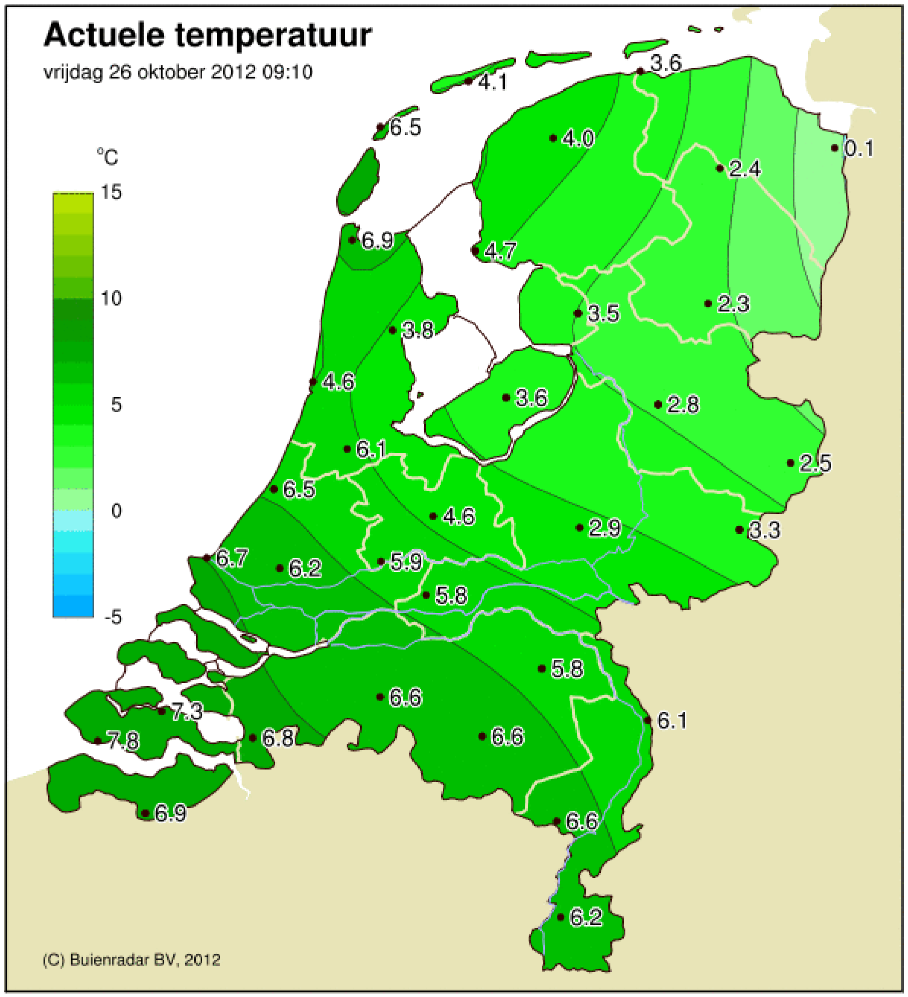
Lectures by Wayne Anderson

LEARNING GOALS

- The meaning of thermal equilibrium, and what thermometers really measure.
- How different types of thermometers unction.
- The physics behind the absolute, or Kelvin, temperature scale.
- How the dimensions of an object change as a result of a temperature change.
- The meaning of heat, and how it differs from temperature.
- How to do calculations that involve heat flow, temperature changes, and changes of phase.
- How heat is transferred by conduction, convection, and radiation.

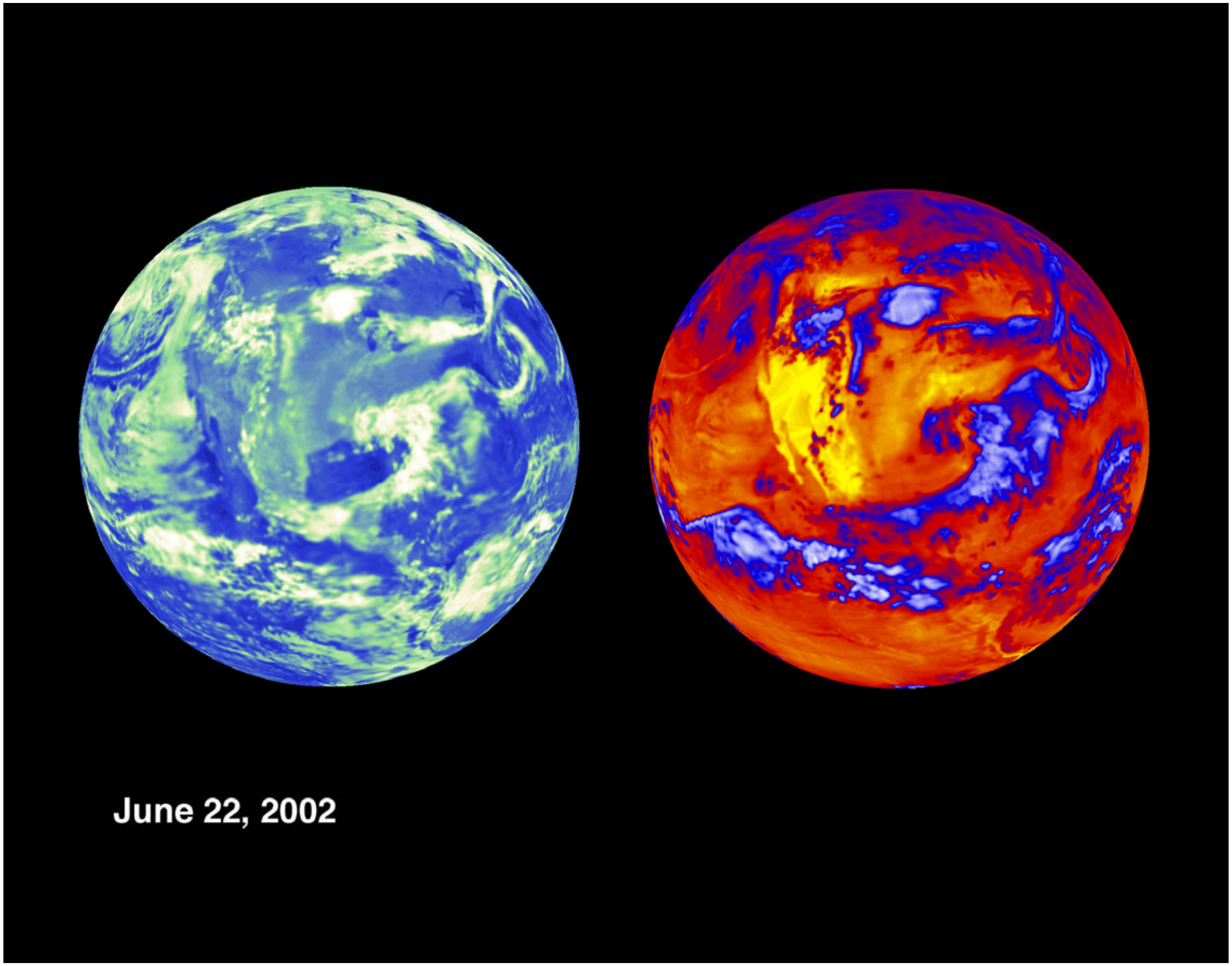
Temperature

- **Weather forecast**



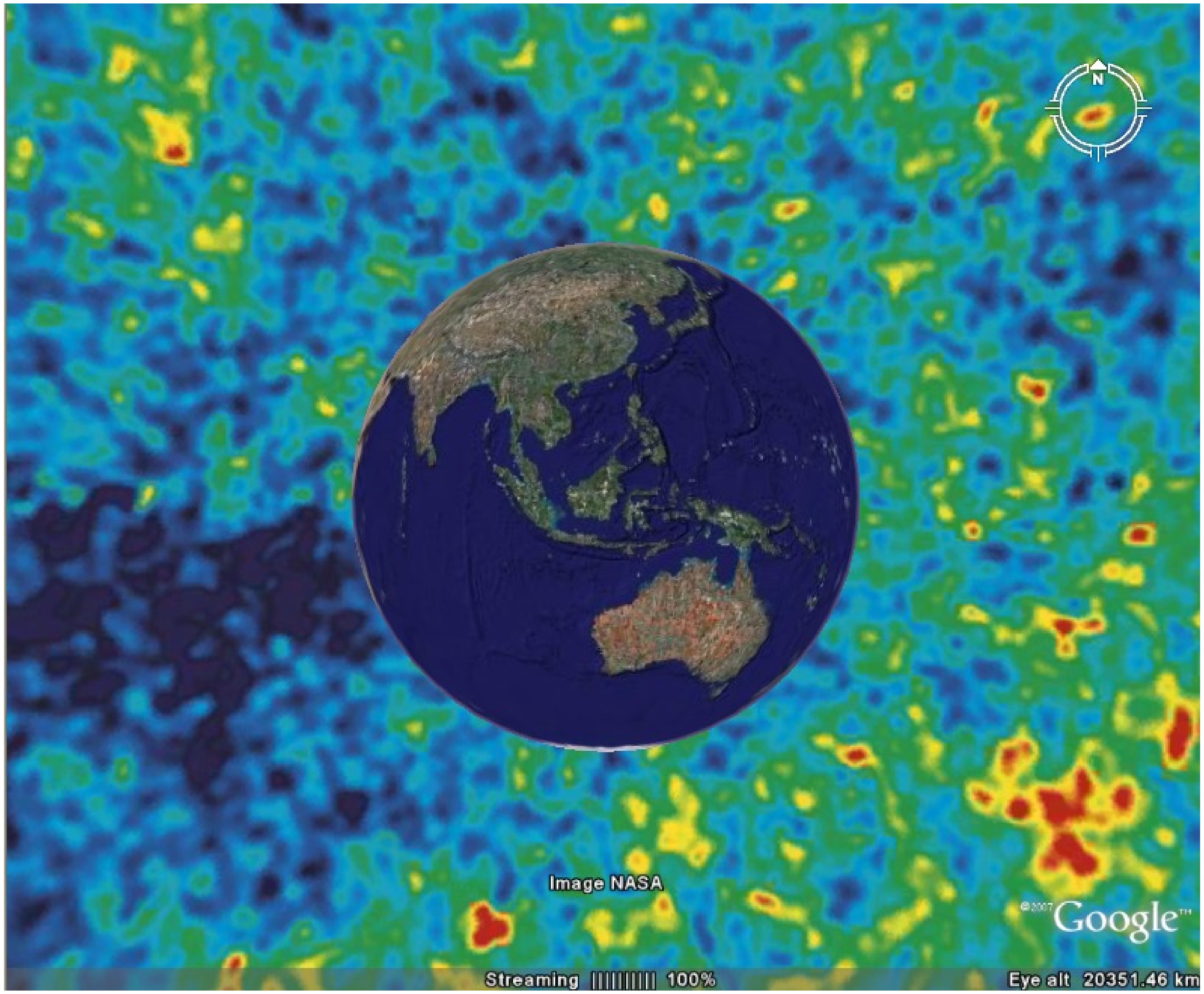
ZO	MA	DI	WO	DO	VR	ZA	ZO
02-12	03-12	04-12	05-12	06-12	07-12	08-12	09-12
5° C	7° C	7° C	3° C	3° C	8° C	5° C	4° C
-1° C	0° C	2° C	0° C	-2° C	0° C	2° C	2° C
N	N	N	N	N	N	N	N
26 km/u	32 km/u	42 km/u	22 km/u	30 km/u	39 km/u	41 km/u	19 km/u
4 Bft	5 Bft	6 Bft	4 Bft	4 Bft	5 Bft	6 Bft	3 Bft
1 mm	3,4 mm	3 mm	1,6 mm	0,2 mm	4,1 mm	9 mm	2,4 mm
57%	72%	56%	52%	23%	63%	64%	47%

Temperature



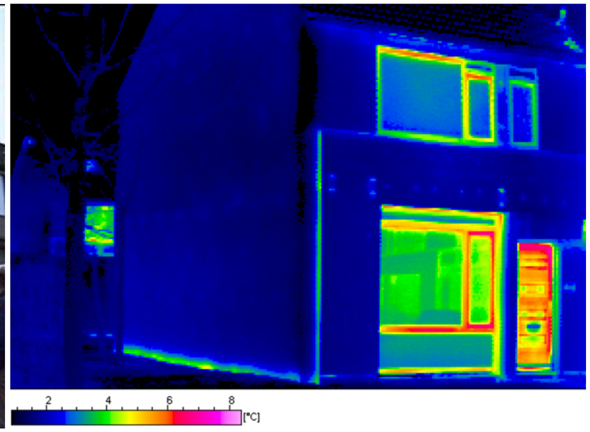
Temperature

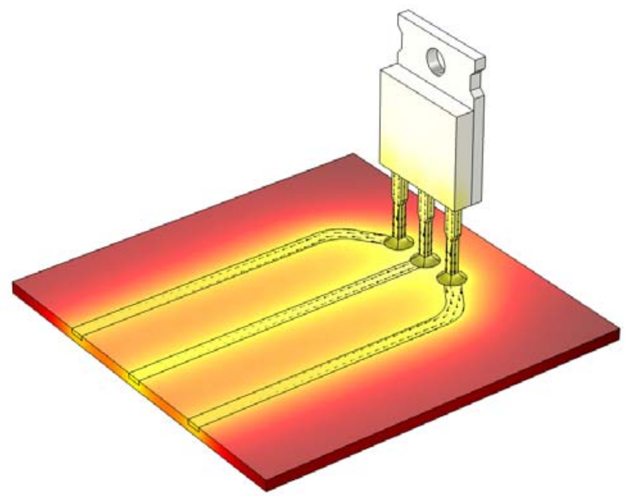
Cosmic background radiation 2.7 K: Proof of Big Bang initial temperature 3000K



Temperature

- **buildings**





Temperature

same temperature

tiles

carpet

'COLD'

'WARM'

- Our senses: qualitative indication of temperature (heat flux)
- Need a reliable and reproducible method for measuring the relative hotness or coldness of objects.

We need a technical definition of temperature.

Thermal Contact and Thermal Equilibrium

1. Two objects are in thermal contact with each other if energy can be exchanged between them.

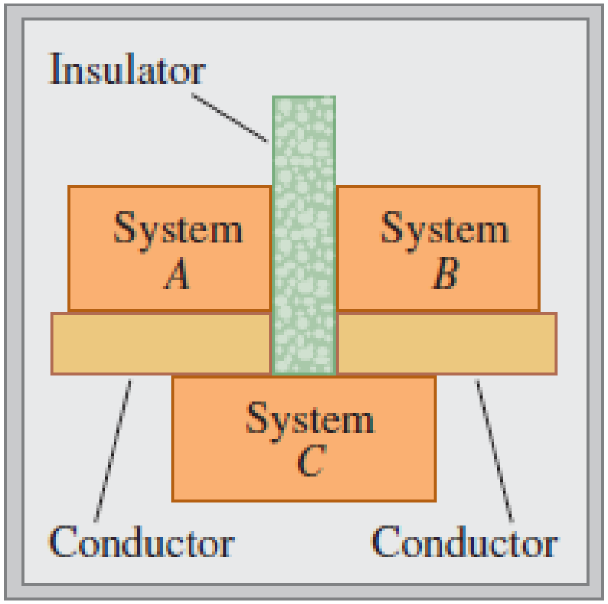
   The exchanges we will focus on will be in the form of heat or electromagnetic radiation.

2. The energy is exchanged due to a temperature difference.
3. Thermal equilibrium is a situation in which two objects would not exchange energy by heat or electromagnetic radiation if they were placed in thermal contact.

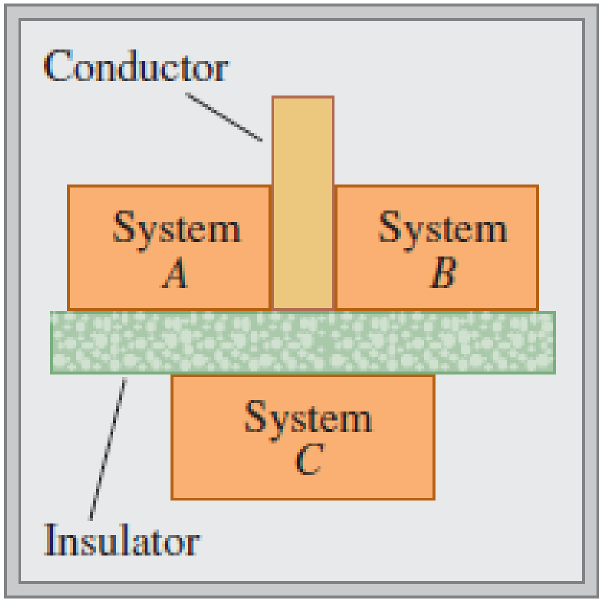
   The thermal contact does not have to also be physical contact.

The zeroth law of thermodynamics

(a) If systems A and B are each in thermal equilibrium with system C …



(b) … then systems A and B are in thermal equilibrium with each other.



The zeroth law of thermodynamics

If C is initially in thermal equilibrium with both A and B, then A and B are also in thermal equilibrium with each other.

Thermometers

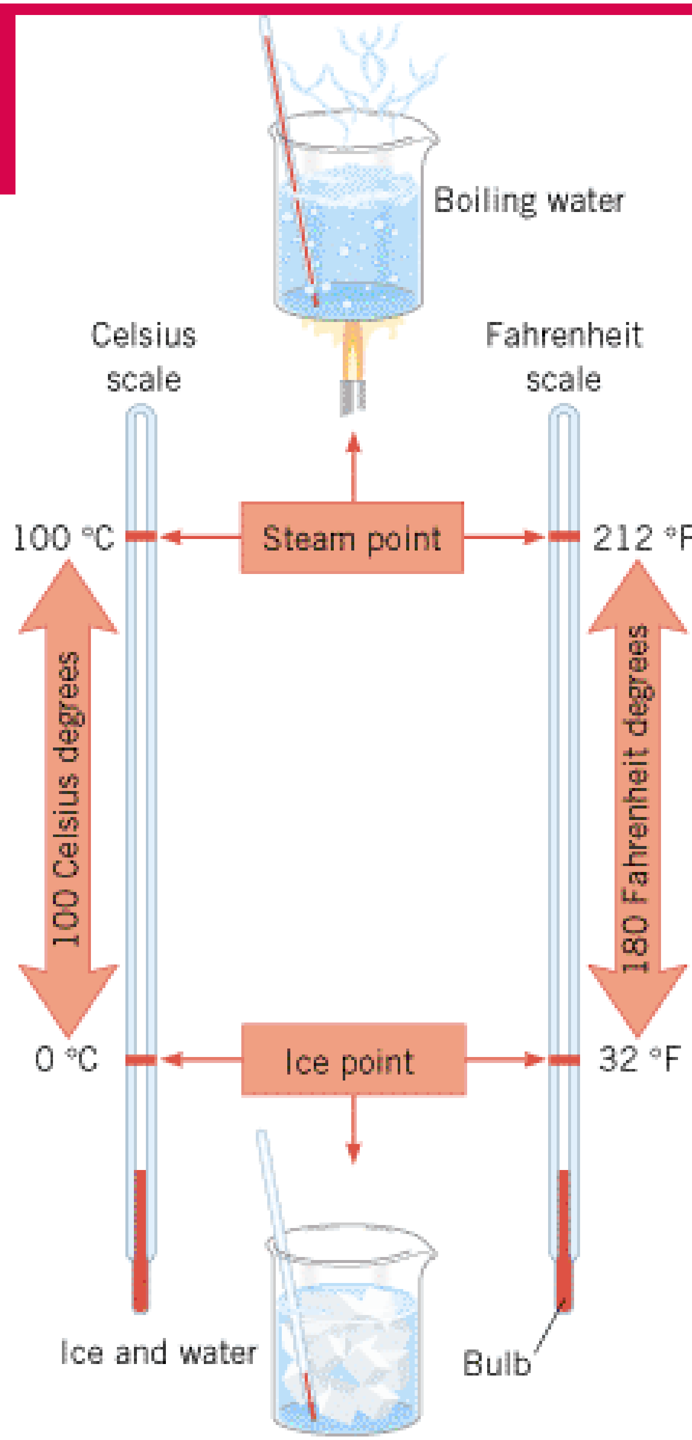
Two systems are in thermal equilibrium if and only if they have the same temperature

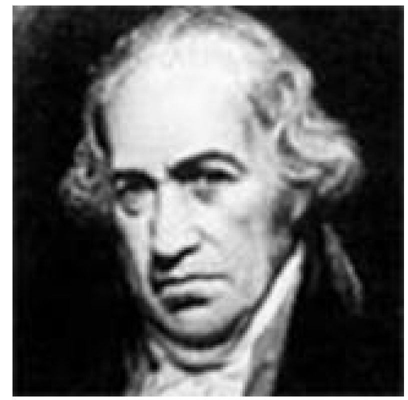
- A thermometer is a device that is used to measure the temperature of a system

- Thermometers are based on the principle that some physical property of a system changes as the system's temperature changes:
  - The volume of a liquid
  - The dimensions of a solid
  - The pressure of a gas at a constant volume
  - The volume of a gas at a constant pressure
  - The electric resistance of a conductor
  - The color of an object

Anders Celsius
1701 – 1744

Swedish astronomer

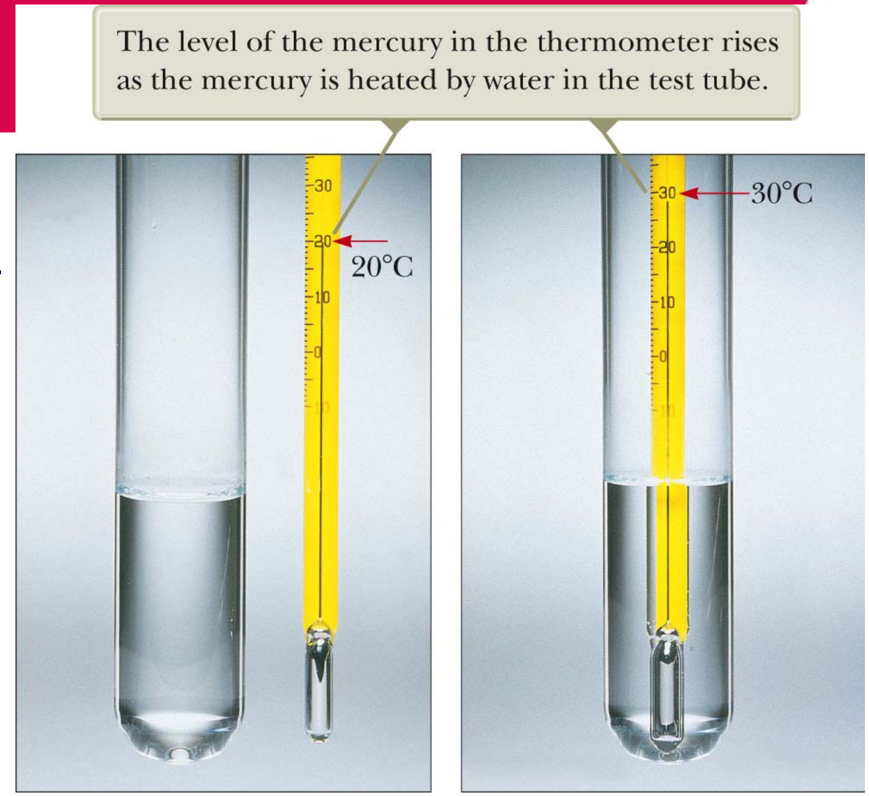




Daniel Gabriel Fahrenheit
1686 – 1736

German physicist

Thermometers



- A common type of thermometer is a liquid-in-glass.
- The material in the capillary tube expands as it is heated.
- The liquid is usually mercury or alcohol.

PROBLEMS

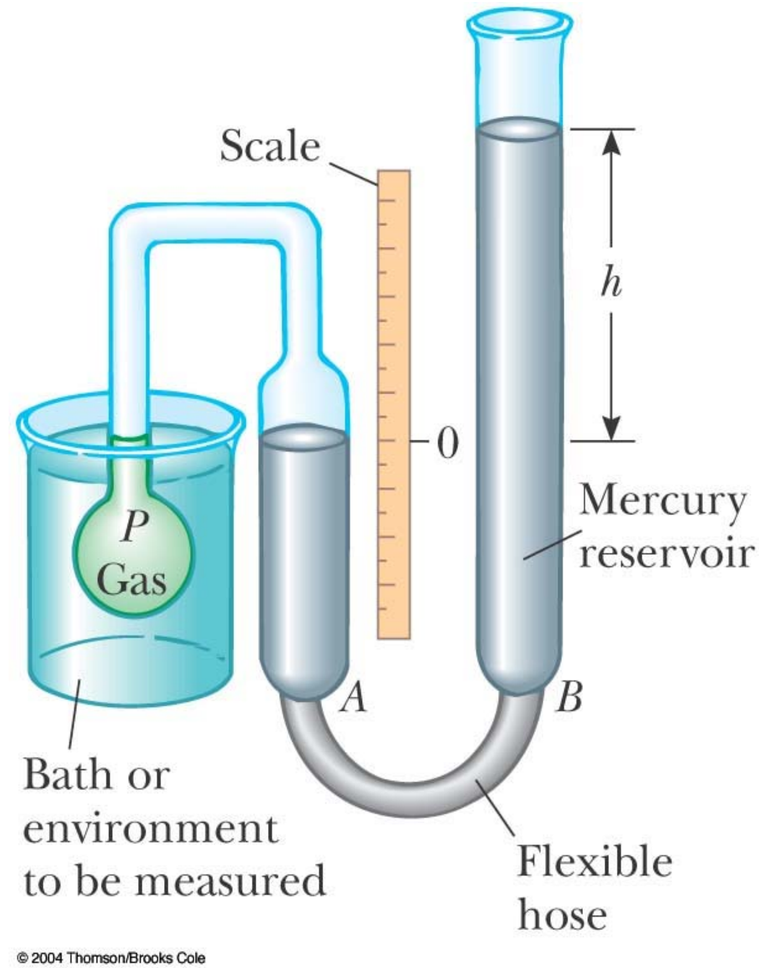
- An alcohol thermometer and a mercury thermometer may agree only at the calibration points.
- The discrepancies when temperatures measured far from the calibration points.
- The thermometers also have a limited range;
    - Mercury cannot be used under –39° C
    - Alcohol cannot be used above 85° C

Constant Volume Gas Thermometer

The physical change exploited is the variation of pressure of a fixed volume gas as its temperature changes

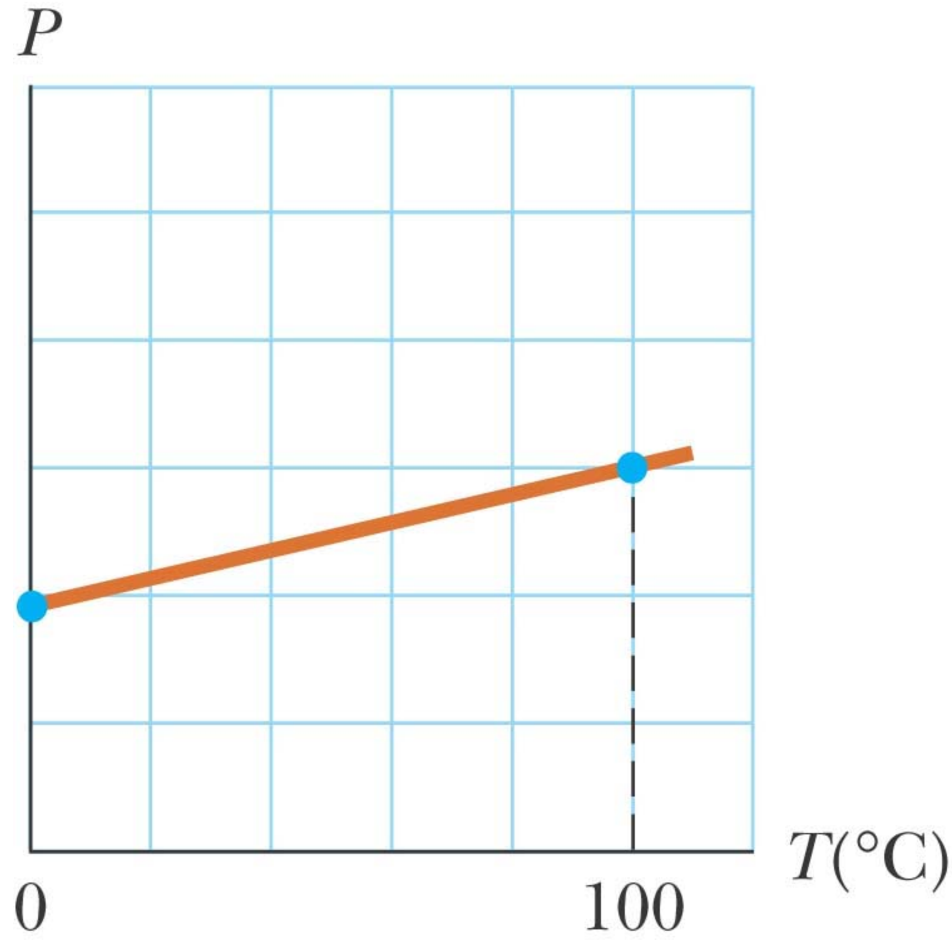
The volume of the gas is kept constant by raising or lowering the reservoir B to keep the mercury level at A constant

Ideal gas law
$pV=nRT$



Constant Volume Gas Thermometer

- To find the temperature of a substance, the gas flask is placed in thermal contact with the substance
- The pressure is found on the graph
- The temperature is read from the graph



Ice bath

Steam bath

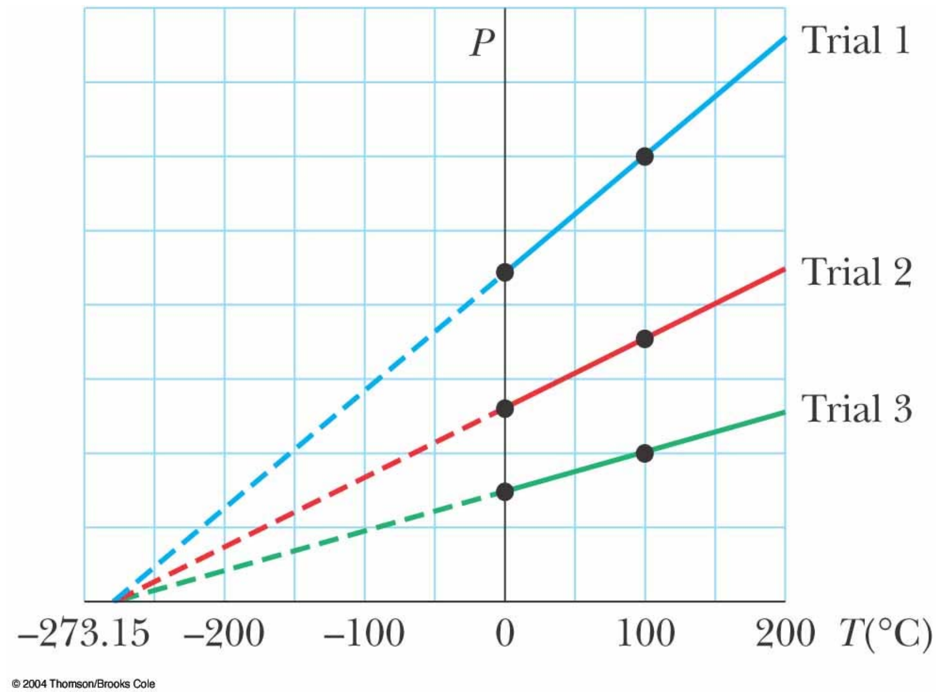
Absolute Zero

The thermometer readings are virtually independent of the gas used

If the lines for various gases are extended, the pressure is always zero when the temperature is

–273.15° C.

This temperature is called *absolute zero*



Absolute Temperature Scale, cont.

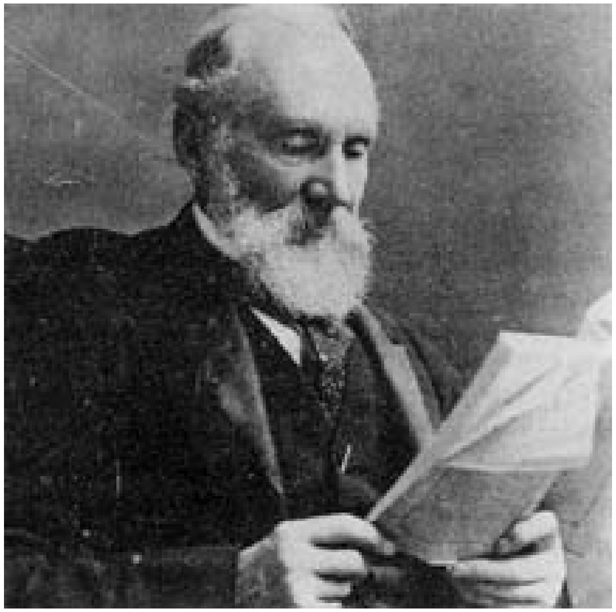
The absolute scale is also called the Kelvin scale.

•The triple point temperature is 273.16 K.

(this is the combination of temperature and pressure where ice, water, and steam can all coexist).

(No degree symbol is used with kelvins)

•The kelvin is defined as 1/273.16 of the difference between absolute zero and the temperature of the triple point of water.



William Thomson
(Lord Kelvin)
1824 – 1907

Scottish mathematician and physicist

Comparison of Scales

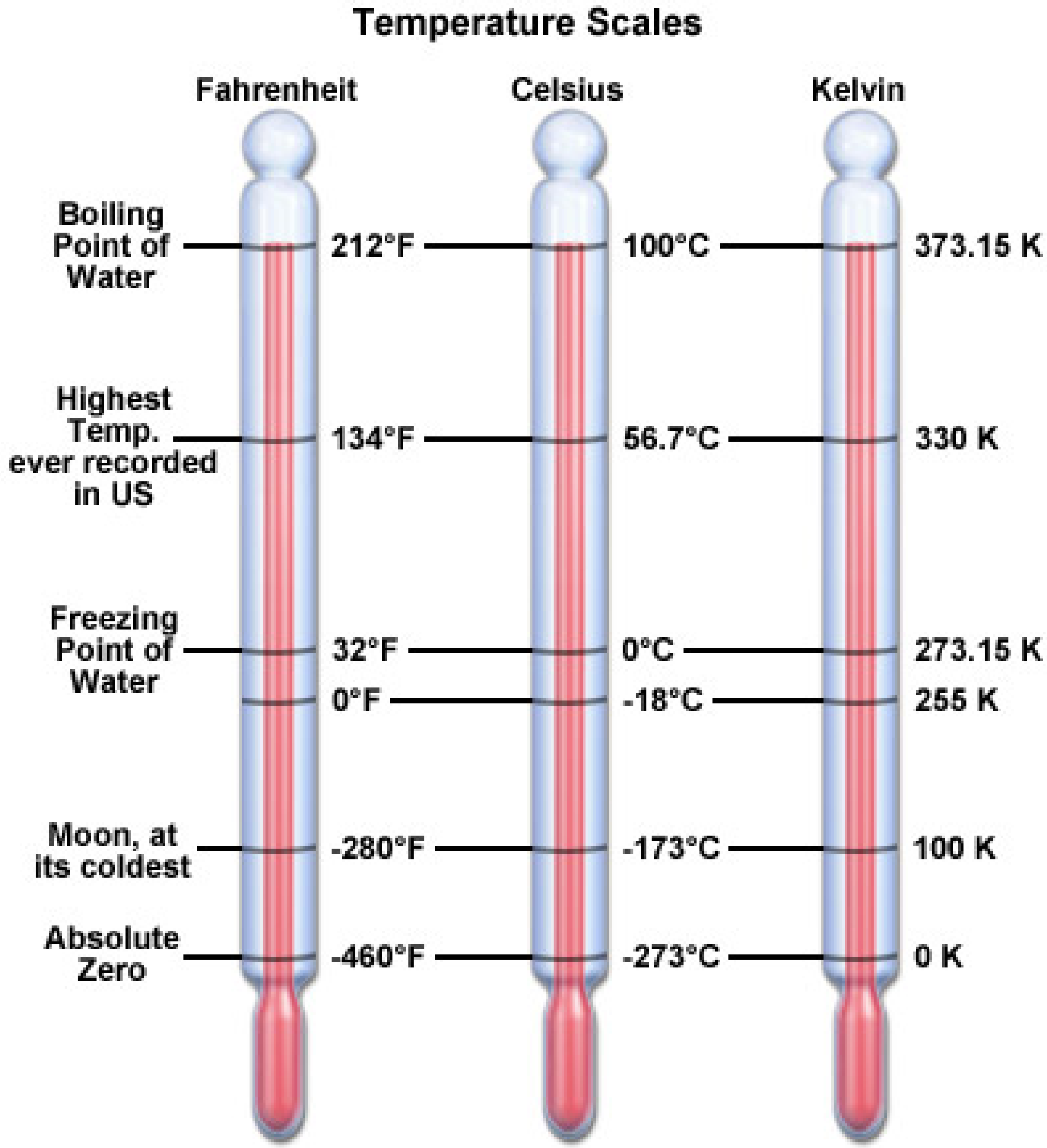
- Celsius and Kelvin have the same size degrees, but different starting points.
  - $T_C = T - 273.15$
- Celsius and Fahrenheit have different sized degrees and different starting points.

$$\Delta T_C = \Delta T = \frac{5}{9}\Delta T_F$$

- To compare changes in temperature

$$T_F = \frac{9}{5}T_C + 32^\circ F$$

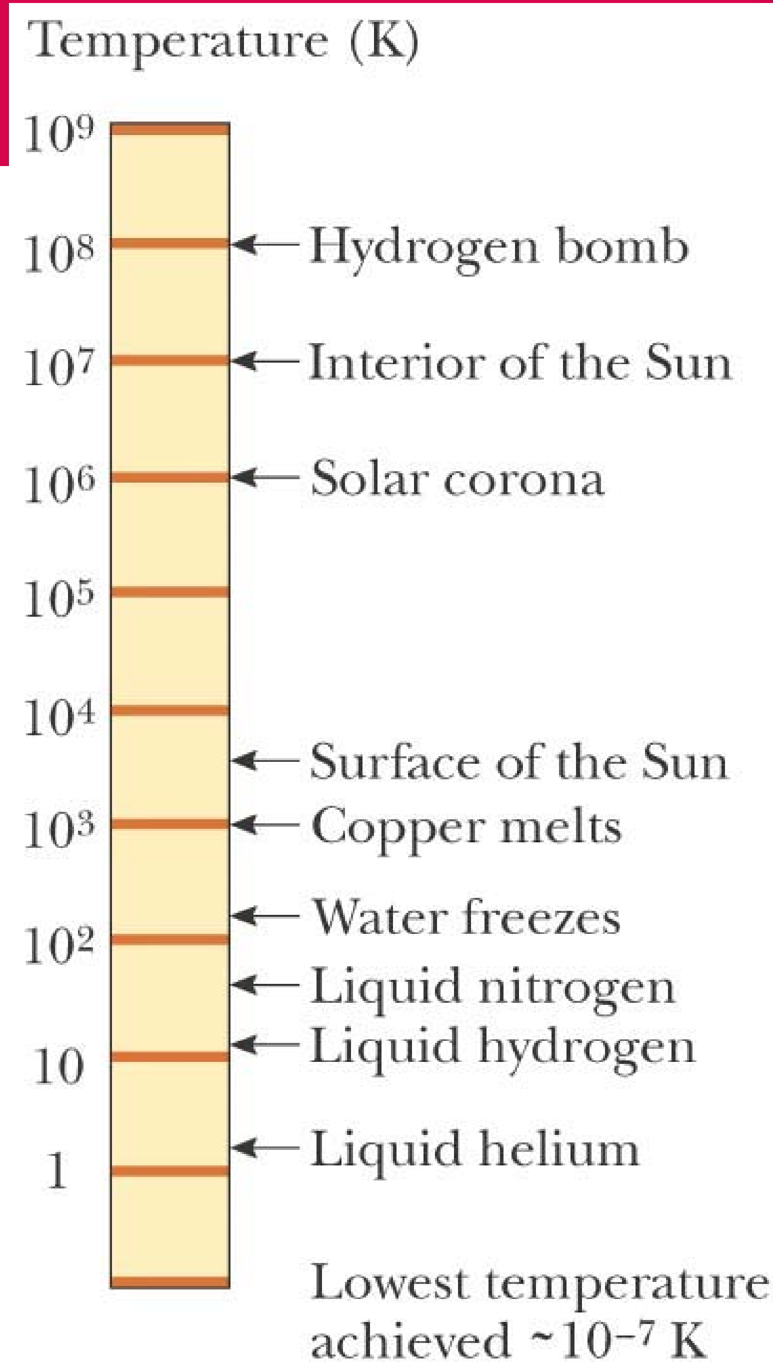
- Ice point temperatures
  - $0^oC = 273.15\ K = 32^o\ F$
- Steam point temperatures
  - $100^oC = 373.15\ K = 212^o\ F$


Temperature Scales
Fahrenheit
Celsius
Kelvin
Boiling Point of Water
212°F
100°C
373.15 K
Highest Temp. ever recorded in US
134°F
56.7°C
330 K
Freezing Point of Water
32°F
0°C
273.15 K
0°F
-18°C
255 K
Moon, at its coldest
-280°F
-173°C
100 K
Absolute Zero
-460°F
-273°C
0 K

•The figure at right gives some absolute temperatures at which various physical processes occur

•The scale is logarithmic

•The temperature of absolute zero cannot be achieved, experiments have come close.

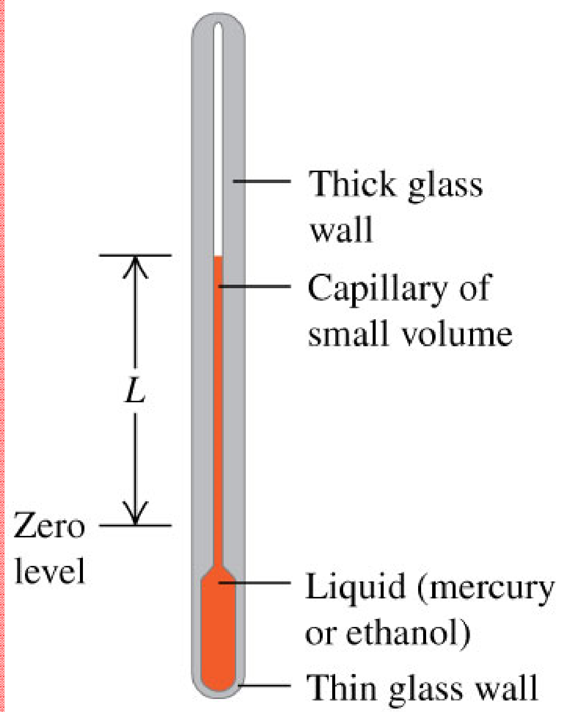


Quiz

The illustration shows a thermometer that uses a column of liquid (usually mercury or ethanol) to measure air temperature. In thermal equilibrium, this thermometer measures the temperature of

1. the column of liquid.
2. the glass that encloses the liquid.
3. the air outside the thermometer.
4. both 1. and 2.
5. all of 1., 2., and 3.

(a) Changes in temperature cause the liquid's volume to change.



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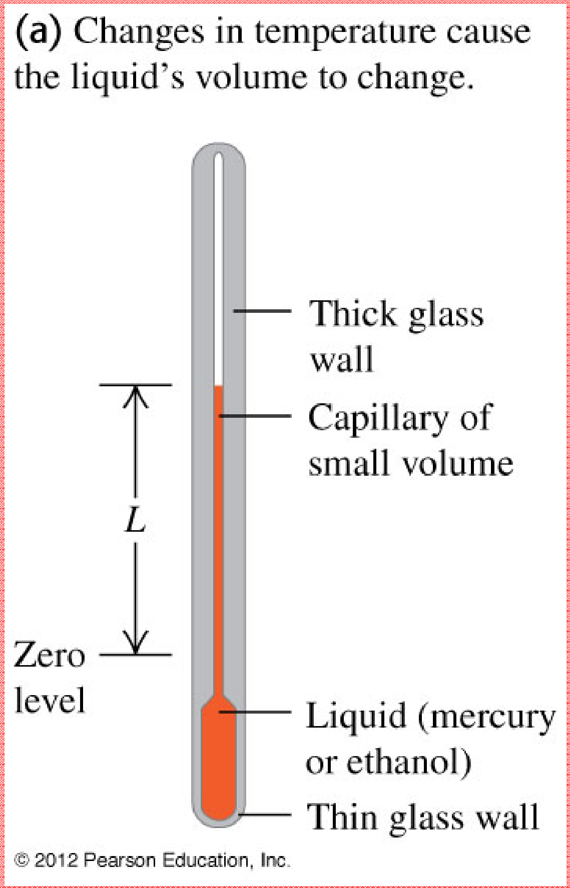
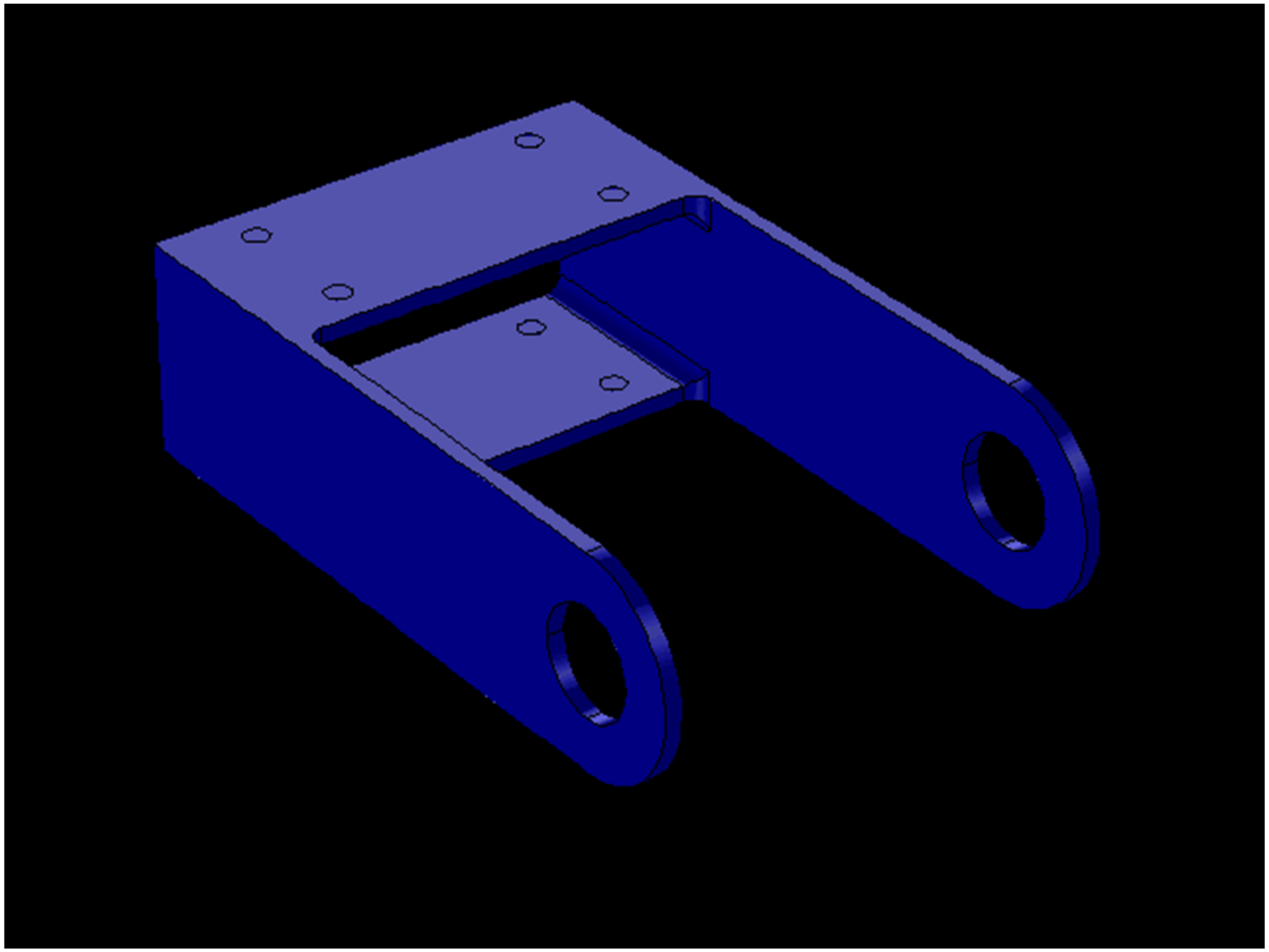


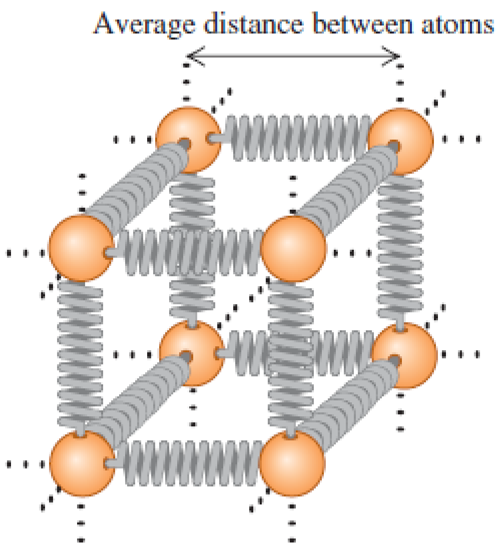
Thermal expansion

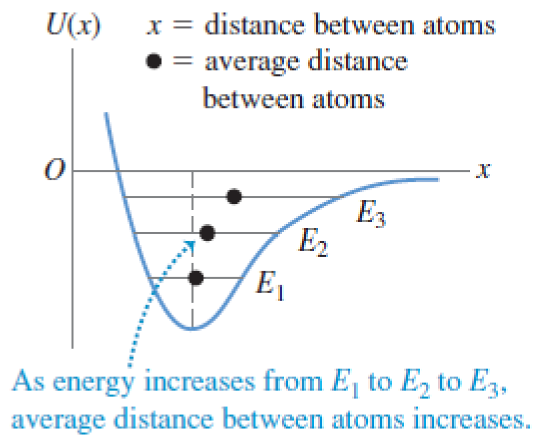
Thermal expansion



Thermal expansion

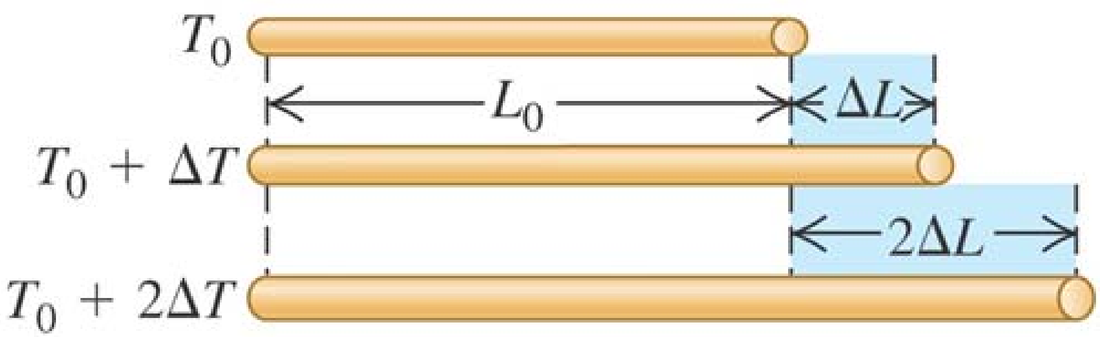
- Thermal expansion is the increase in the size of an object with an increase in its temperature
- Thermal expansion is a consequence of the change in the average separation between the atoms in an object
- If the expansion is small relative to the original dimensions of the object, the change in any dimension is, to a good approximation, proportional to the first power of the change in temperature



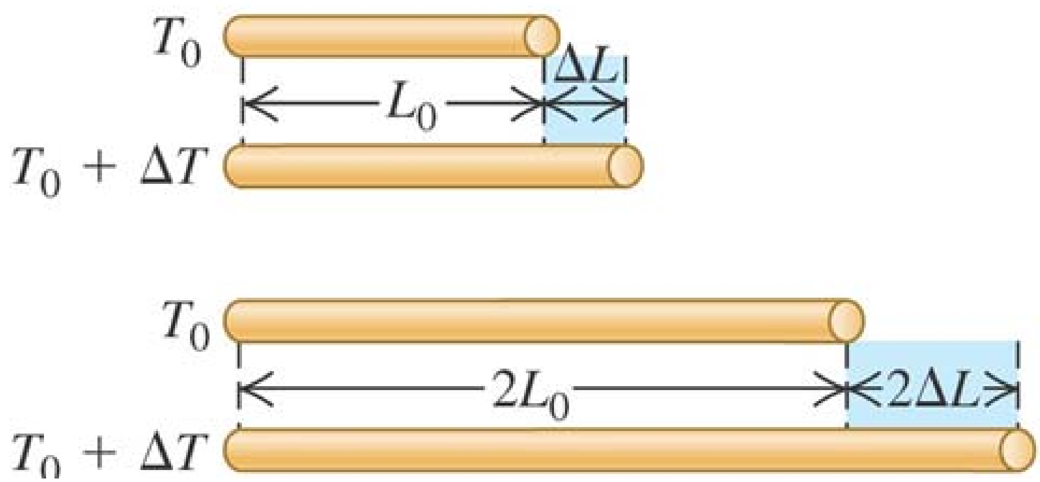


Linear thermal expansion

(a) For moderate temperature changes, ΔL is directly proportional to ΔT.



(b) ΔL is also directly proportional to L_0.



Linear thermal expansion

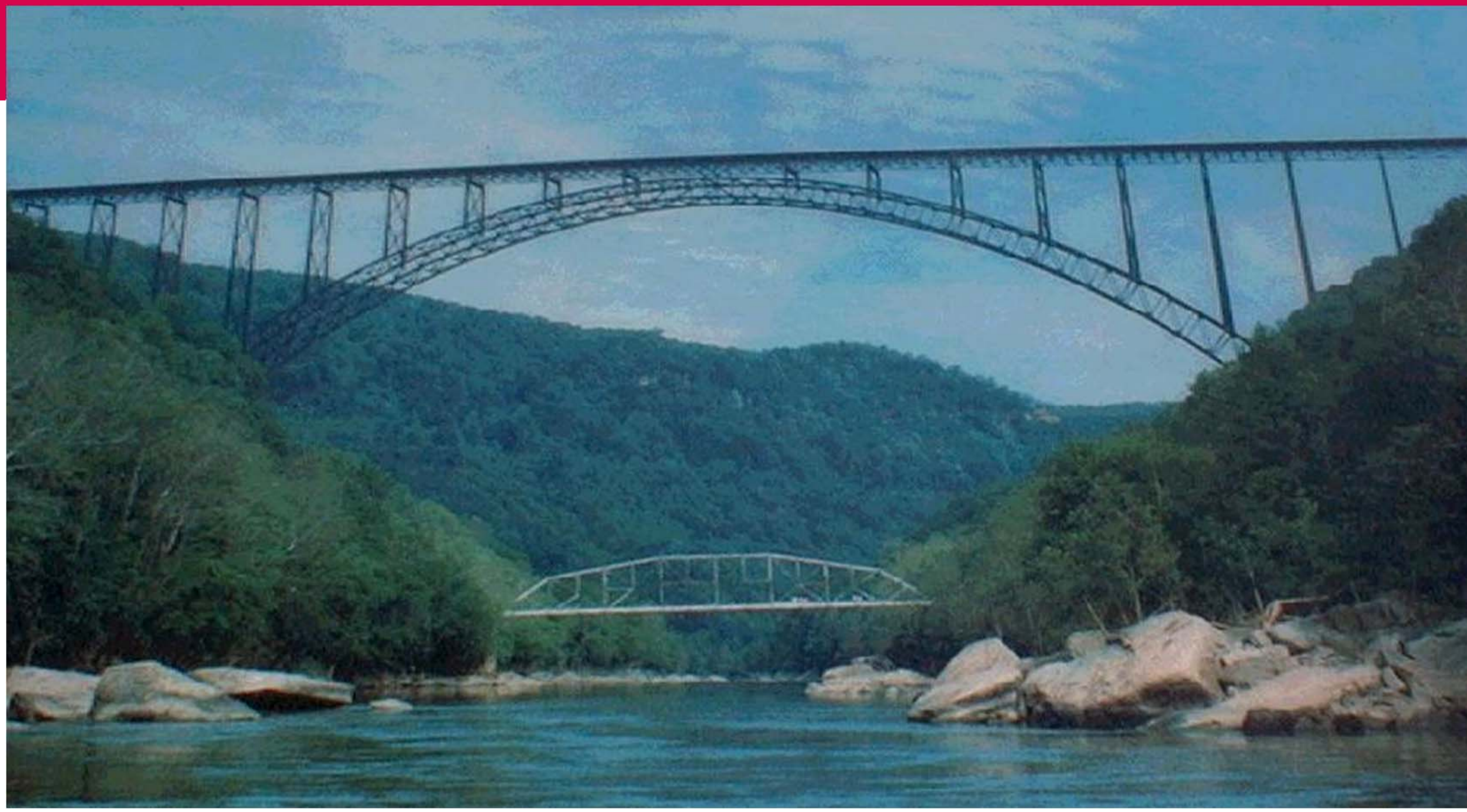
Assume an object has an initial length *L.* That length increases by ΔL as the temperature changes by ΔT. We define the coefficient of linear expansion as

$$\alpha = \frac{\Delta L / L_i}{\Delta T}$$

More confinent:

$$\Delta L = \alpha L_0 \Delta T \qquad L = L_0(1 + \alpha \Delta T)$$

The *coefficient of linear expansion*, α, has units of **(°C)$^{-1}$**



The New River Gorge Bridge in West Virginia is a steel arch bridge 518 m in length. ($\alpha = 11 \times 10^{-6}$/C)

How much does its length change between temperature extremes of -10.0° C and +35.0° C

The New River Gorge Bridge in West Virginia is a steel arch bridge 518 m in length. (alpha=11 x 10^{-6}/C)

How much does its length change between temperature extremes of -20.0° C and +35.0° C

$$L = L_0(1 + \alpha \Delta T)$$

Summer: ΔL= 11 10^{-6} 518 (35-20) = 0.085 m

Winter: ΔL= 11 10^{-6} 518 (-10-20) = -0.17 m

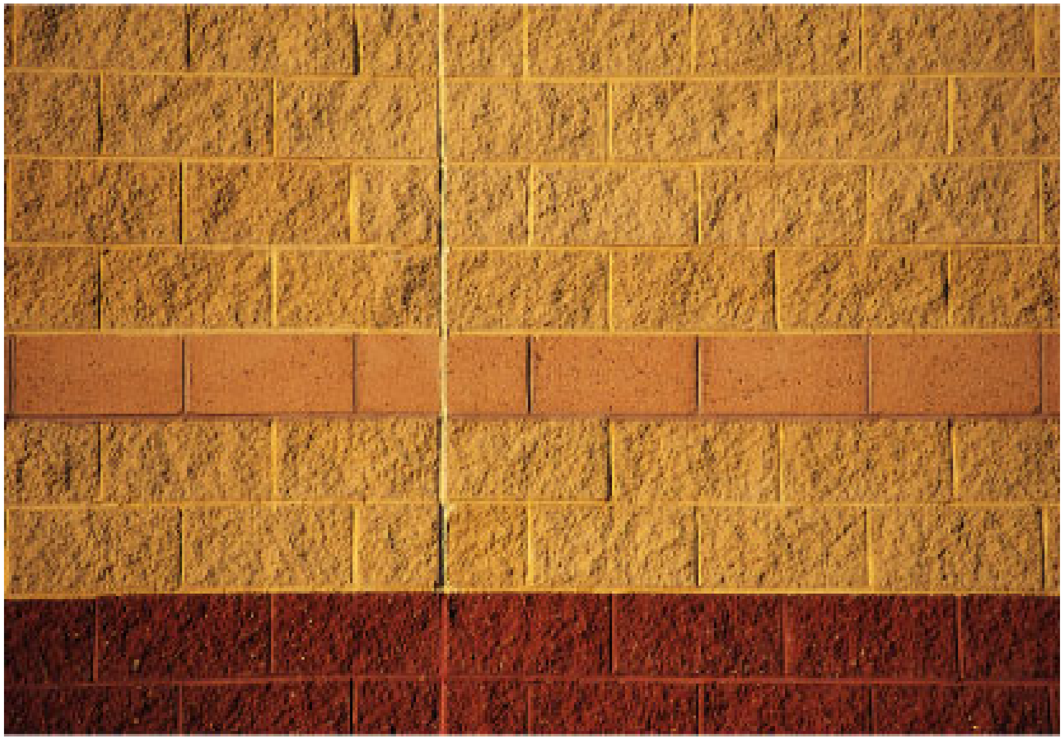
Dilatation joint 25 cm

Expansion Joint in a Bridge.

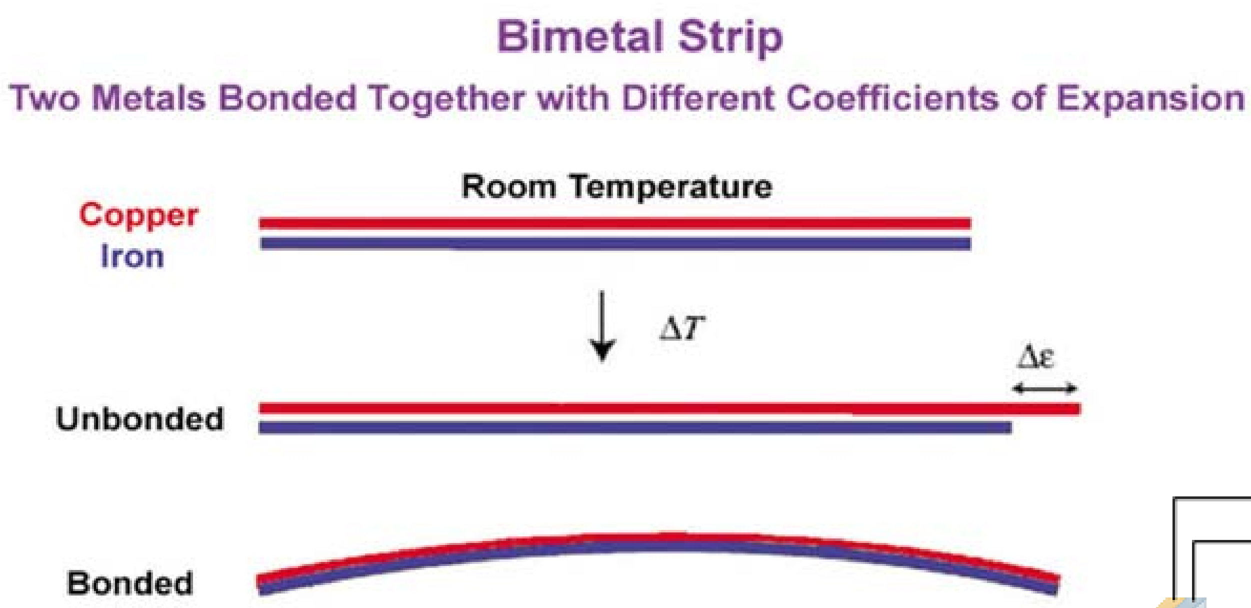
Thermal Expansion, Example

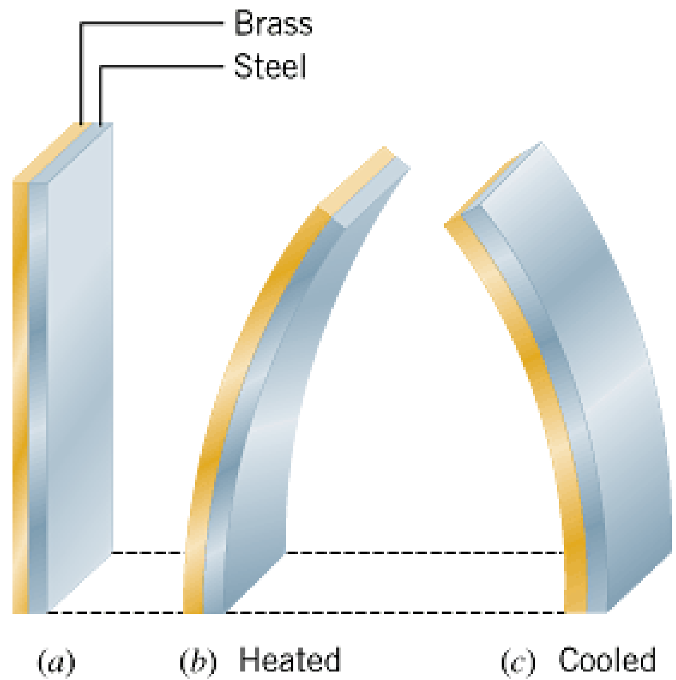
In many situations, joints are used to allow room for thermal expansion

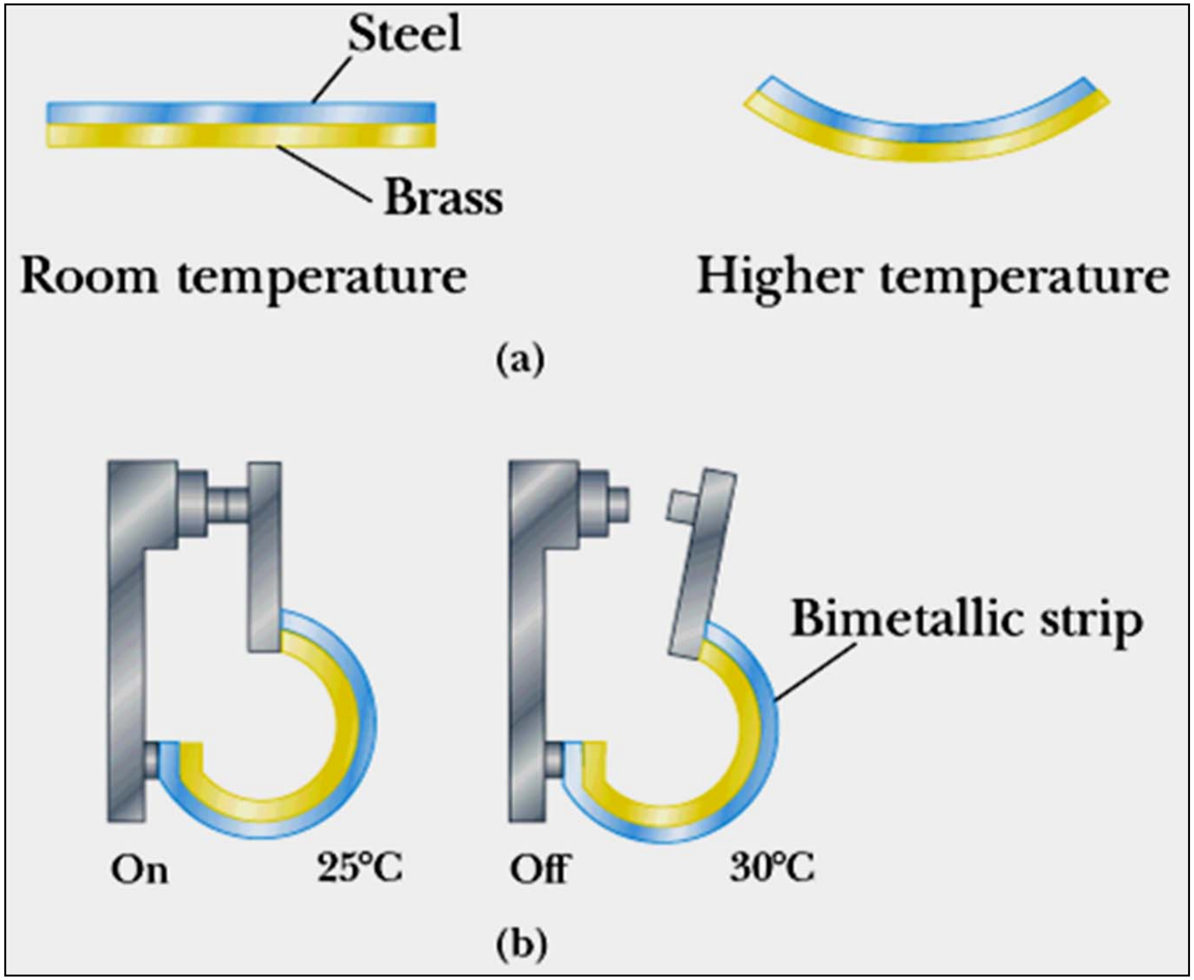
The long, vertical joint is filled with a soft material that allows the wall to expand and contract as the temperature of the bricks changes

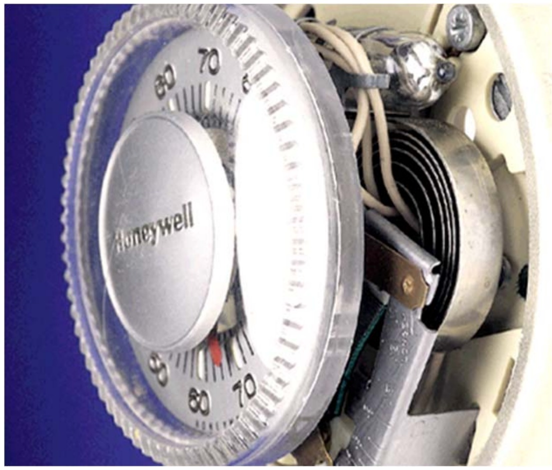


Applications



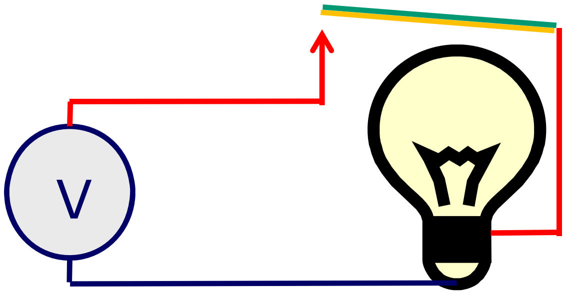




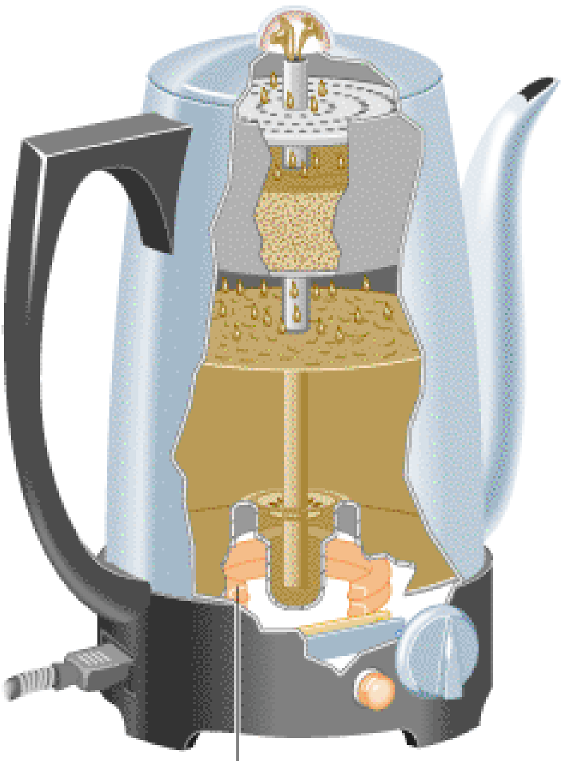


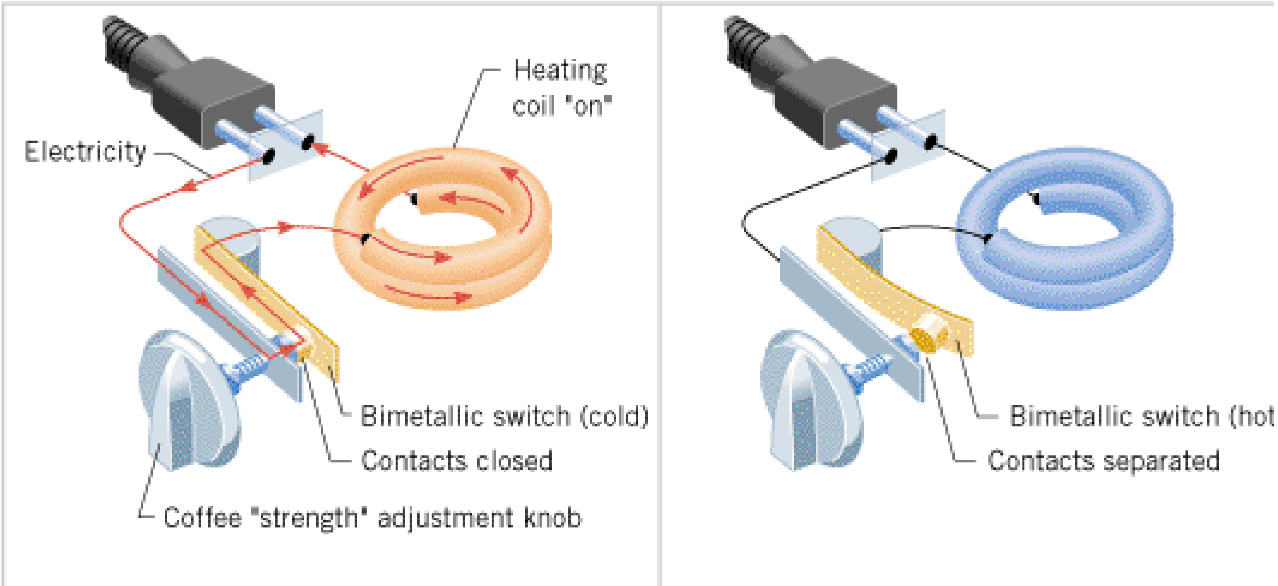
Electric contact switches the gas burner

Blinking light



Bimetallic Switch: overheating protection





(*a*) Coffee pot "on" (*b*) Coffee pot "off"

A bimetallic strip controls whether this coffee pot is (*a*) “on” (strip cool, straight) or (*b*) “off” (strip hot, bent).

(d)

Rail lines buckled due to unanticipated scorching heat wave occurred in Melbourne, Australia.

Area thermal expansion

$$L = L_0(1 + \alpha \Delta T)$$

The area A_0 of an object changes by an amount ΔA when its temperature changes by an amount ΔT:

$$A = L^2 = \left[L_0(1 + \alpha \Delta T)\right]^2$$

$$A = L^2 = L_0{}^2(1 + 2\alpha \Delta T + \cancel{\alpha^2 \Delta T^2})$$

$$\Delta A = 2\alpha A_0 \Delta T$$

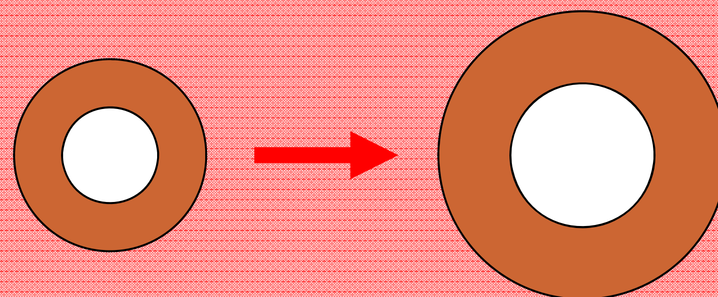
where α is the coefficient of linear expansion.

Quiz

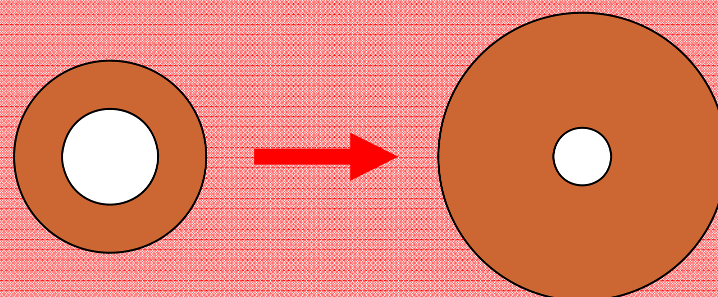
A solid object has a hole in it. Which of these illustrations more correctly shows how the size of the object and the hole change as the temperature increases?

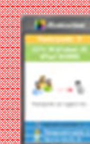
1. illustration #1
2. illustration #2
3. The answer depends on the material of which the object is made.
4. The answer depends on how much the temperature increases.
5. Both 3. and 4. are correct.

#1



#2





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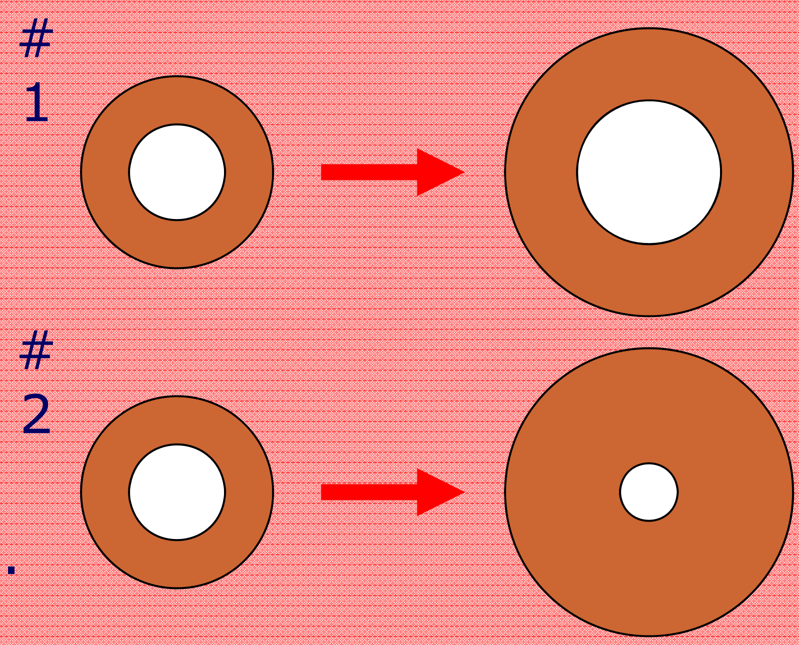
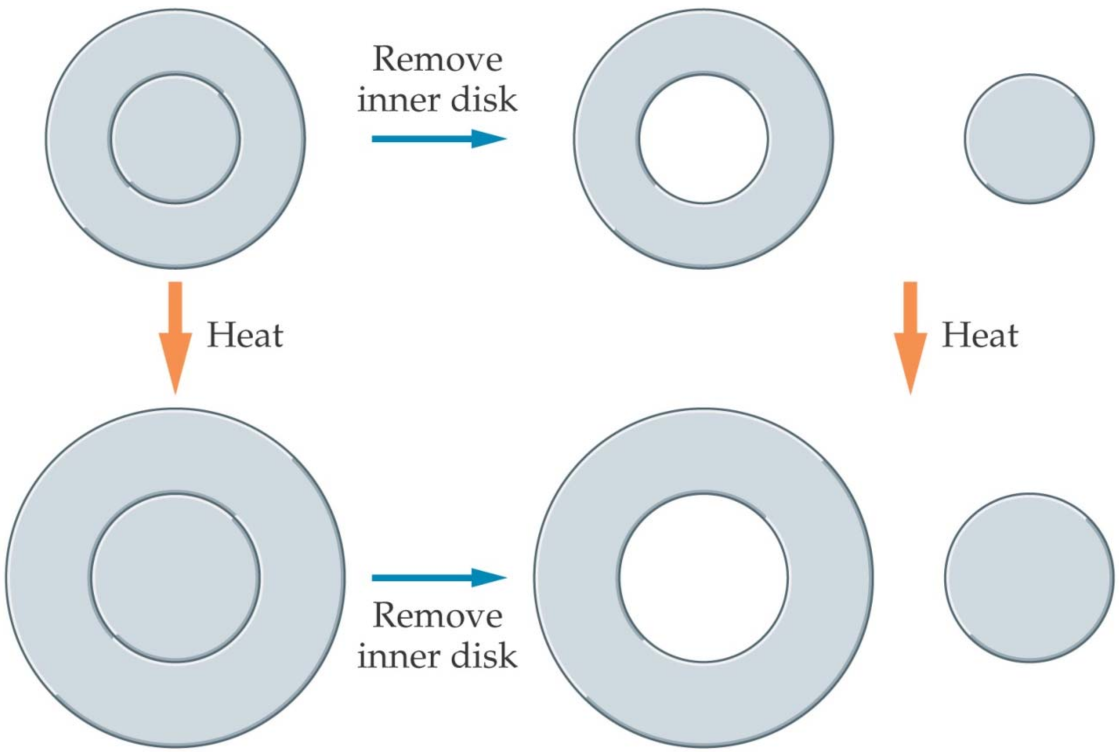


The expansion of an area of a flat substance is derived from the linear expansion in both directions:

$$\Delta A \approx 2\alpha A \Delta T$$

Holes expand as well:



Volume thermal expansion

The volume V_0 of an object changes by an amount ΔV when its temperature changes by an amount ΔT:

$$V = L^3 = \left[L_0(1+\alpha\Delta T)\right]^3$$

$$V = L_0{}^3(1+3\alpha\Delta T \cancel{+ \ldots)}$$

$$\Delta V = 3\alpha V_0 \Delta T$$

where α is the coefficient of linear expansion.

Coefficients of expansion

Table 17.1 Coefficients of Linear Expansion

Material	α [K^{-1} or $(C°)^{-1}$]
Aluminum	2.4×10^{-5}
Brass	2.0×10^{-5}
Copper	1.7×10^{-5}
Glass	$0.4–0.9 \times 10^{-5}$
Invar (nickel–iron alloy)	0.09×10^{-5}
Quartz (fused)	0.04×10^{-5}
Steel	1.2×10^{-5}

Factor 3

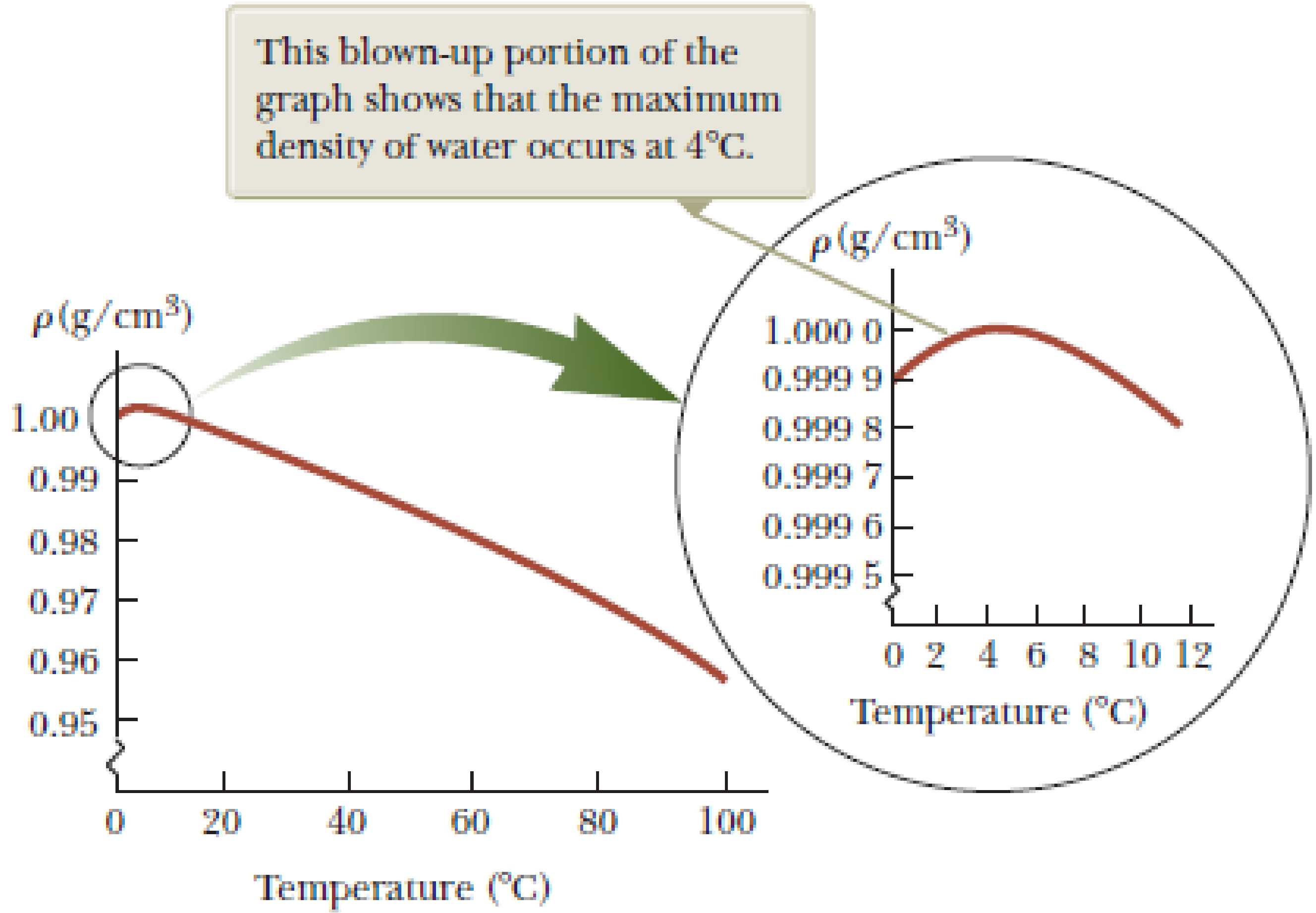
Table 17.2 Coefficients of Volume Expansion

Solids	β [K^{-1} or $(C°)^{-1}$]	Liquids	β [K^{-1} or $(C°)^{-1}$]
Aluminum	7.2×10^{-5}	Ethanol	75×10^{-5}
Brass	6.0×10^{-5}	Carbon disulfide	115×10^{-5}
Copper	5.1×10^{-5}	Glycerin	49×10^{-5}
Glass	$1.2–2.7 \times 10^{-5}$	Mercury	18×10^{-5}
Invar	0.27×10^{-5}		
Quartz (fused)	0.12×10^{-5}		
Steel	3.6×10^{-5}		

Galileo thermometer

Volume expansion

Coefficients of expansion of water



As the temperature increases from 0°C to 4°C, water contracts

Its density increases

Above 4°C, water expands with increasing temperature

Its density decreases

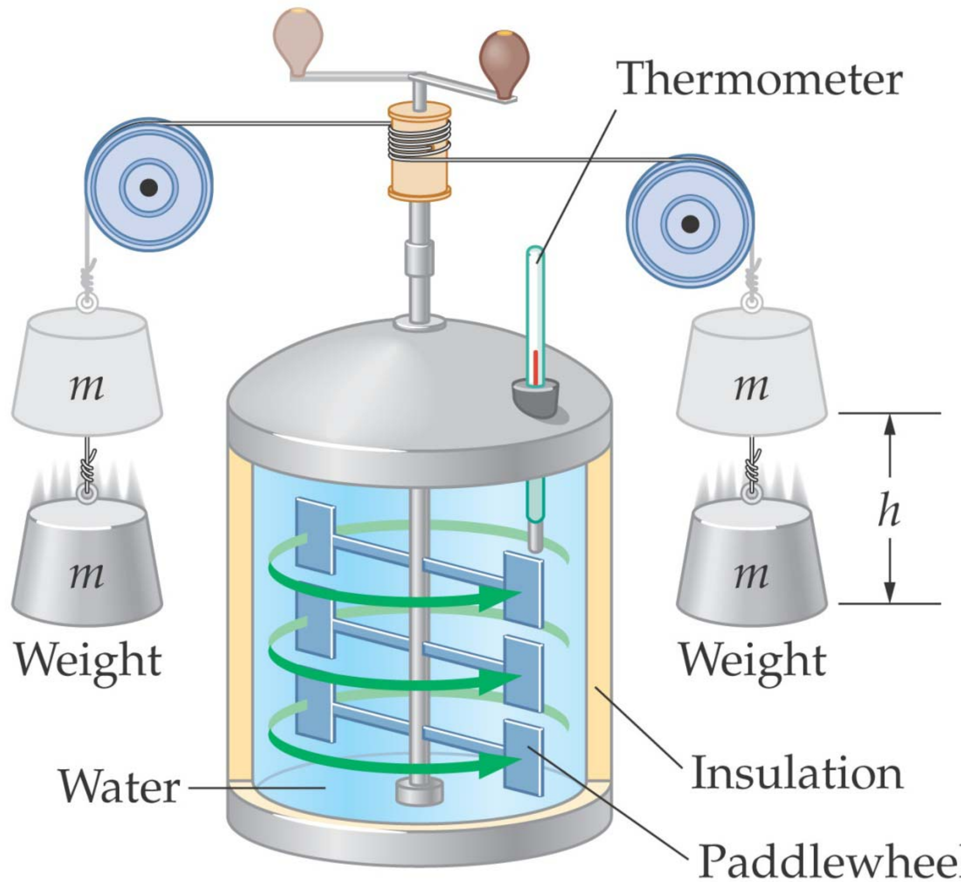
The maximum density of water (1.000 g/cm^3) occurs at 4°C

Heat and work

Experimental work has shown that heat is another form of energy.

James Joule used a device similar to this one to measure the mechanical equivalent of heat:

James Prescott Joule
1818-1889



Temperature and Heat

When heat flows from a hotter object into a colder one, the *internal energy* of the hotter object decreases, and the internal energy of the colder object increases.

The internal energy consists of several forms of molecular kinetic and potential energy. Temperature is ***not*** a measure of an object's total internal energy.

Temperature and Heat

Does the same amount of heat energy, flowing into or out of a variety of objects, change every object's temperature by the same amount?

No. The change in temperature depends on:

-the amount of heat lost or gained;

-the mass of the object;

-the material that the object is made of.

Temperature and Heat

The material property is called the specific heat capacity:

$$Q = cm\Delta T$$

temperature change

heat required

specific heat capacity

mass

SI units of specific heat capacity: J / (kg C^{o})

Heat: Other Units

calorie (cal): the amount of heat that increases the temperature of 1 gram of water by 1 C°

kilocalorie (kcal): increases 1 kg H_2O by 1 C°

nutritional Calorie: = 1000 regular calories = 1 kcal

British Thermal Unit (BTU): increases the temperature of 1 pound of water by 1F°

1 cal = 4.186 J

1 kcal=1000 cal = 4186 J

1 Btu= 1055J

Quiz

You wish to increase the temperature of a 1.00-kg block of a certain solid substance from 20° C to 25° C. (The block remains solid as its temperature increases.) To calculate the amount of heat required to do this, you need to know

1. the specific heat of the substance.
2. the molar heat capacity of the substance.
3. the heat of fusion of the substance.
4. the thermal conductivity of the substance.
5. more than one of the above

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You wish to increase the temperature of a 1.00-kg block of a certain solid substance from 20° C to 25° C. (The block remains solid as its temperature increases.) To calculate the amount of heat required to do this, you need to know

✓ 1. the specific heat of the substance.

2. the molar heat capacity of the substance.

3. the heat of fusion of the substance.

4. the thermal conductivity of the substance.

5. more than one of the above

Heat and Phase Change

To change the phase of a material (melt ice, freeze water, boil water, condense steam) we must add heat, or remove heat.

At the phase-changing temperatures (melting point or boiling point), heat is added or removed without changing the temperature until the phase change is complete.

Heat and Phase Change

The amount of heat required to accomplish the phase change depends on the mass of material involved, what kind of material it is, and what phase change we are considering.

In general:

heat

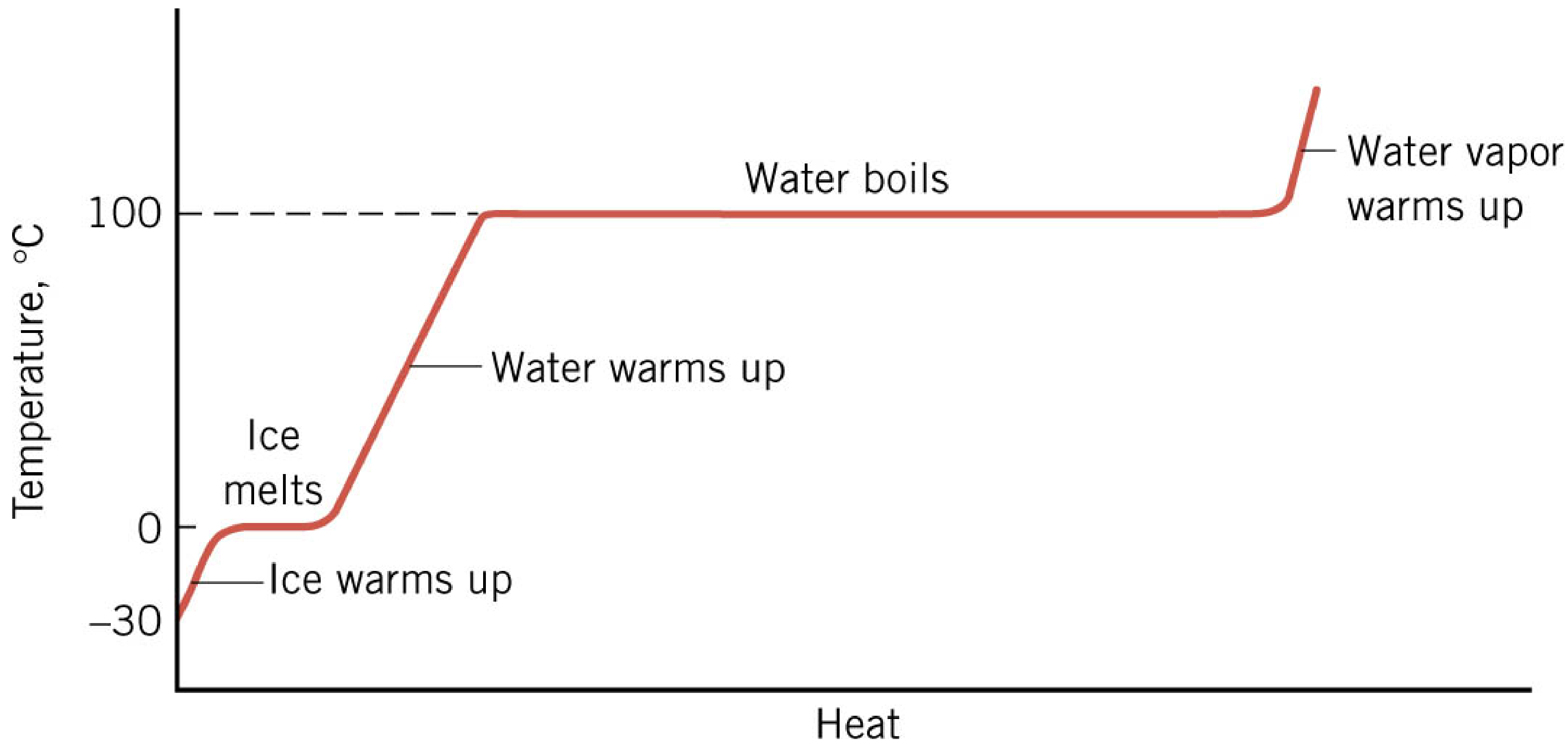
mass

$$Q = mL$$

latent heat

SI units of latent heat: J / kg

Heat and Phase Change of water

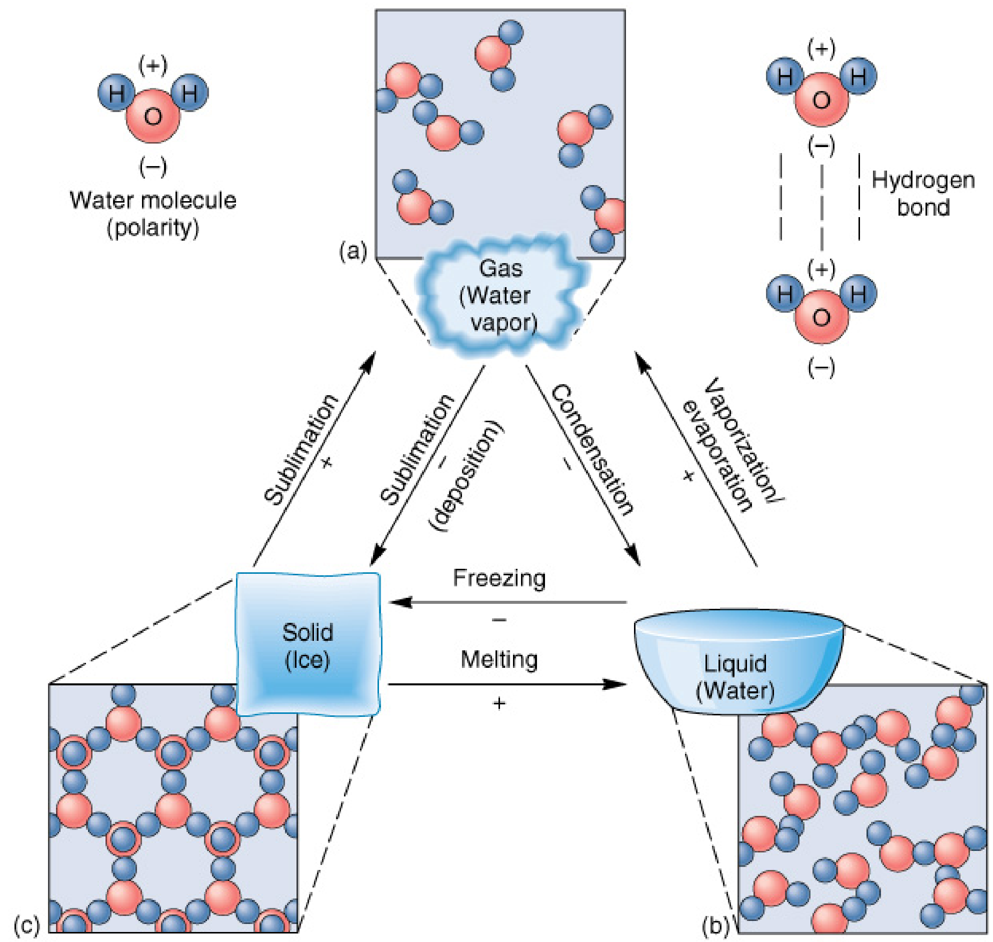


Heat and Phase Change

Phase change names

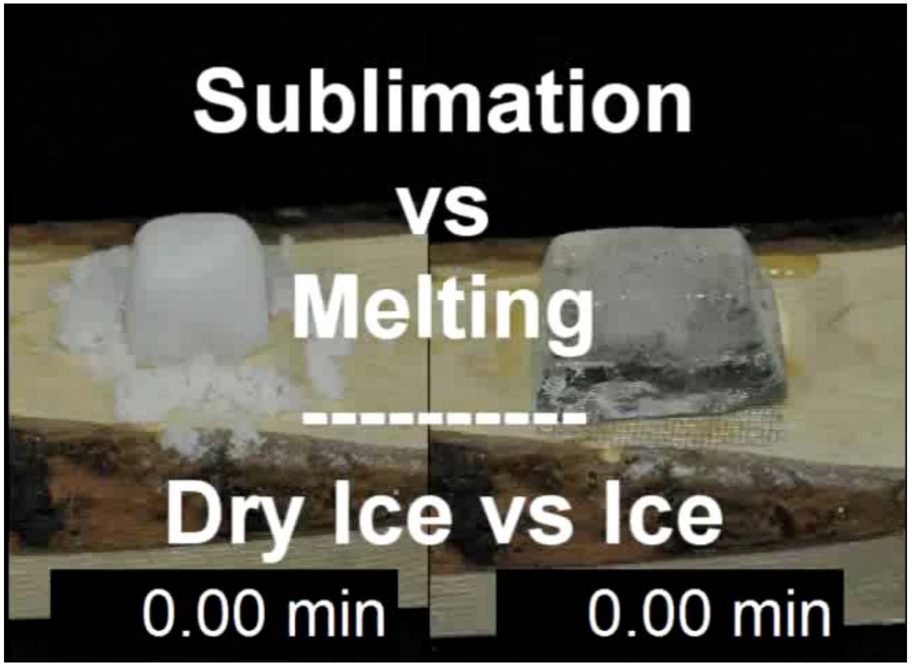
	solid	**liquid**	**gas**
from solid to:	- - - - -	melting (fusion)	sublimation (vaporization)
from liquid to:	freezing (fusion)	- - - - -	boiling or evaporation (vaporization)
from gas to:	condensation (vaporization)	condensation (vaporization)	- - - - -

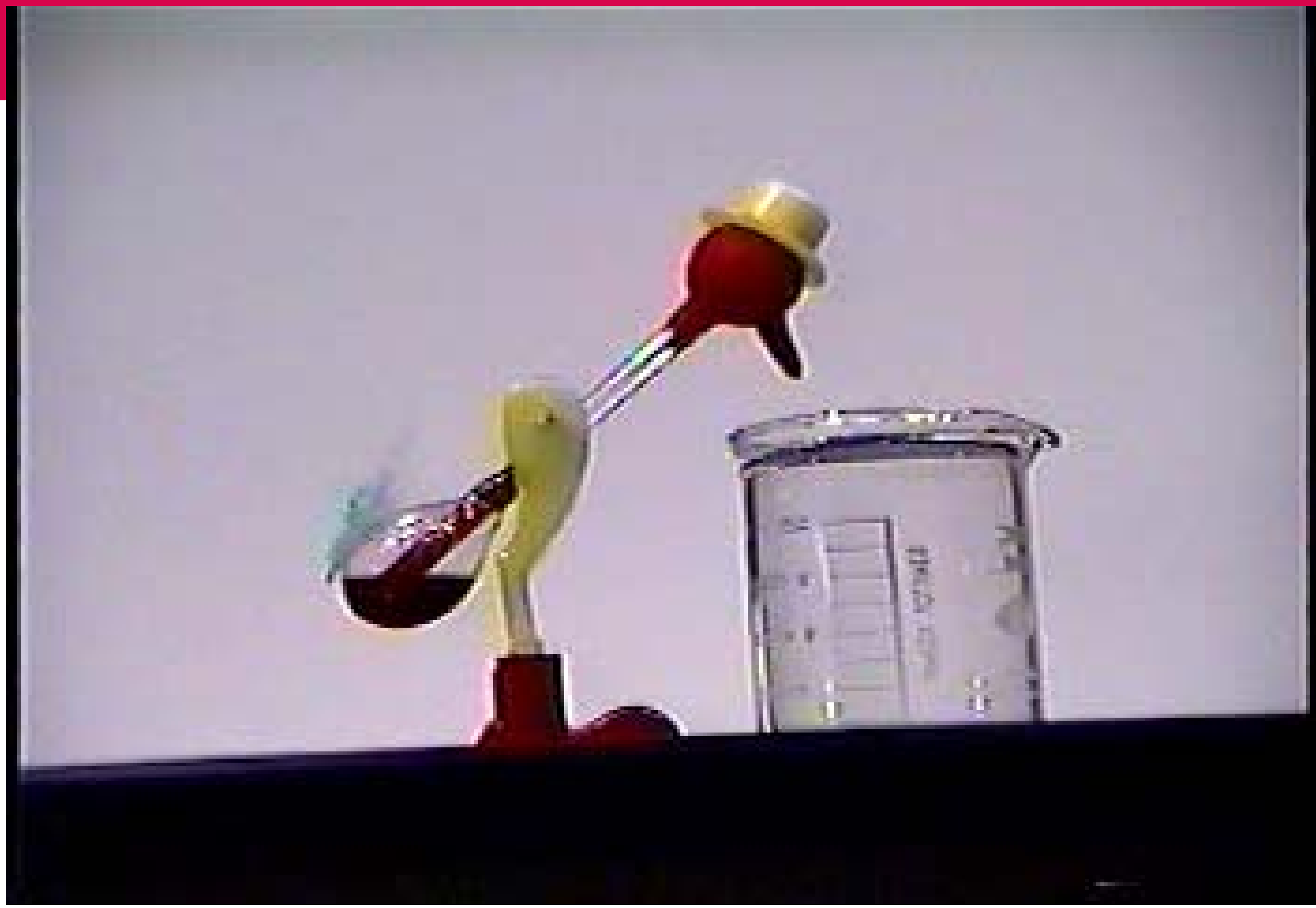
Phase changes water



‘Special’ transitions

Super cooling





As the liquid evaporates from the head of the duck, the liquid in the duck heats up (towards room temp) making it rise up the duck's body. When it passes the CM point of the duck, it tips it over, getting the beak wet again. The cool water cools the liquid and the duck stands back up.

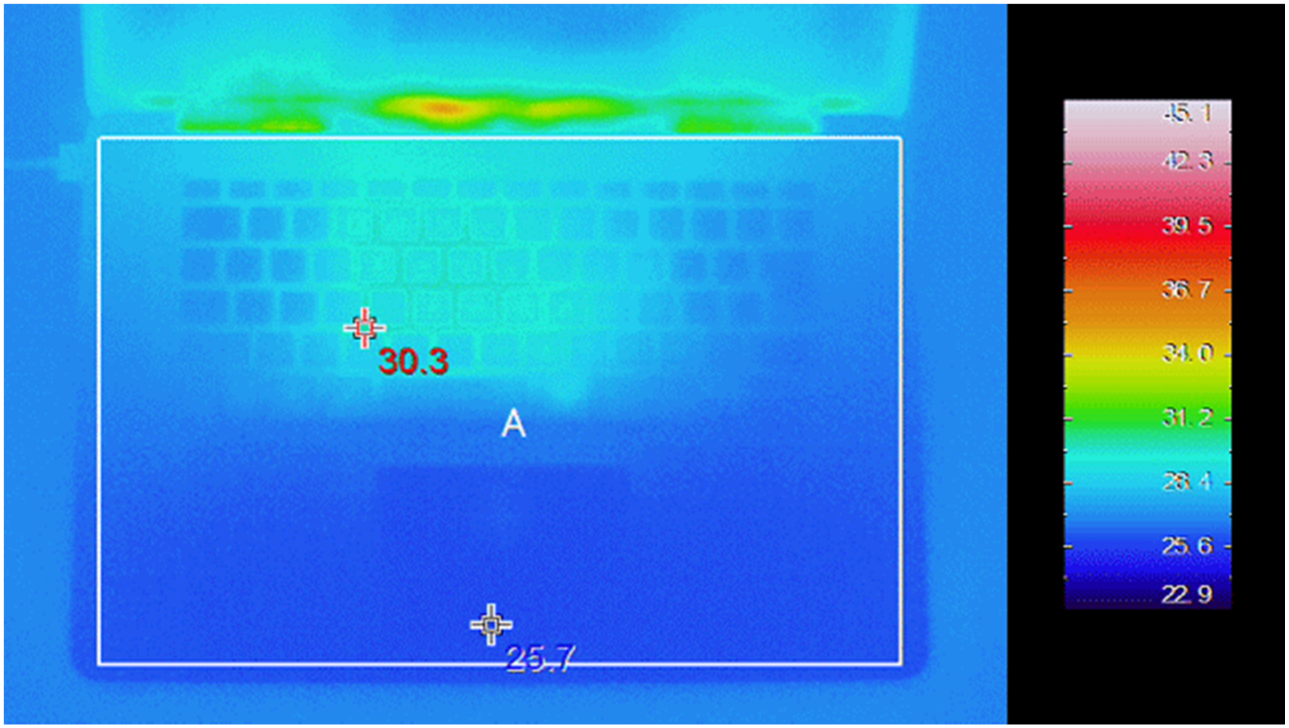
J. Güémez; R. Valiente; C. Fiolhais; M. Fiolhais (December 2003), "Experiments with the drinking bird", American Journal of Physics 71 (12): 1257–1263, Bibcode 2003AmJPh..71.1257G, doi:10.1119/1.1603272

1. The process operates as follows:
2. The water evaporates from the felt on the head.
3. Evaporation lowers the temperature of the glass head (heat of vaporization).
4. The temperature decrease causes some of the dichloromethane vapor in the head to condense.
5. The lower temperature and condensation together cause the pressure to drop in the head (by the ideal gas law).
6. The higher vapor pressure in the warmer base pushes the liquid up the neck.
7. As the liquid rises, the bird becomes top heavy and tips over.
8. When the bird tips over, the bottom end of the neck tube rises above the surface of the liquid.
9. A bubble of warm vapor rises up the tube through this gap, displacing liquid as it goes.
10. Liquid flows back to the bottom bulb (the toy is designed so that when it has tipped over the neck's tilt allows this), and pressure equalizes between the top and bottom bulbs
11. The weight of the liquid in the bottom bulb restores the bird to its vertical position
12. The liquid in the bottom bulb is heated by ambient air, which is at a temperature slightly higher than the temperature of the bird's head

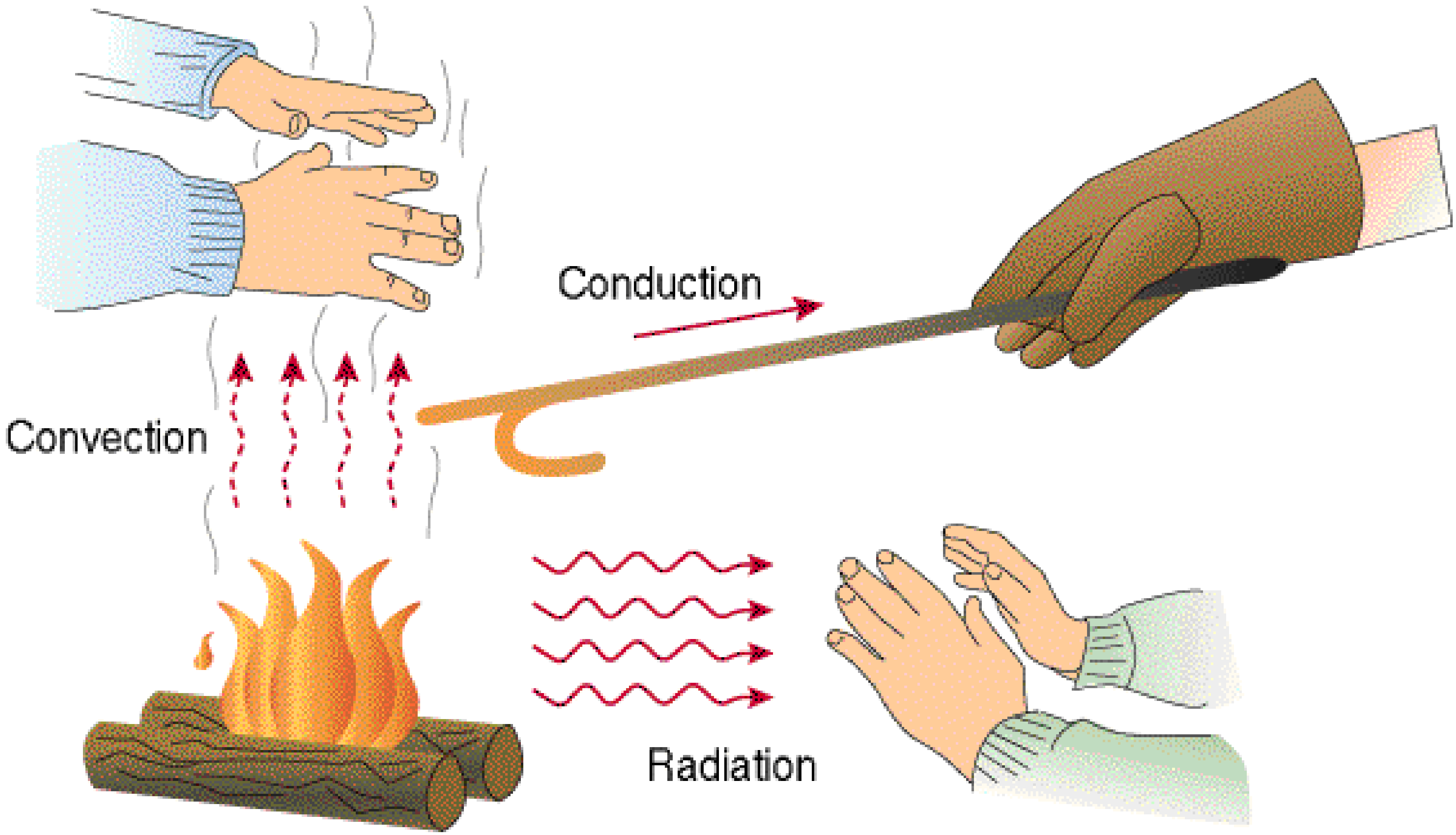
World energy problem

http://www.youtube.com/watch?v=Rq3K6Ma0wIU

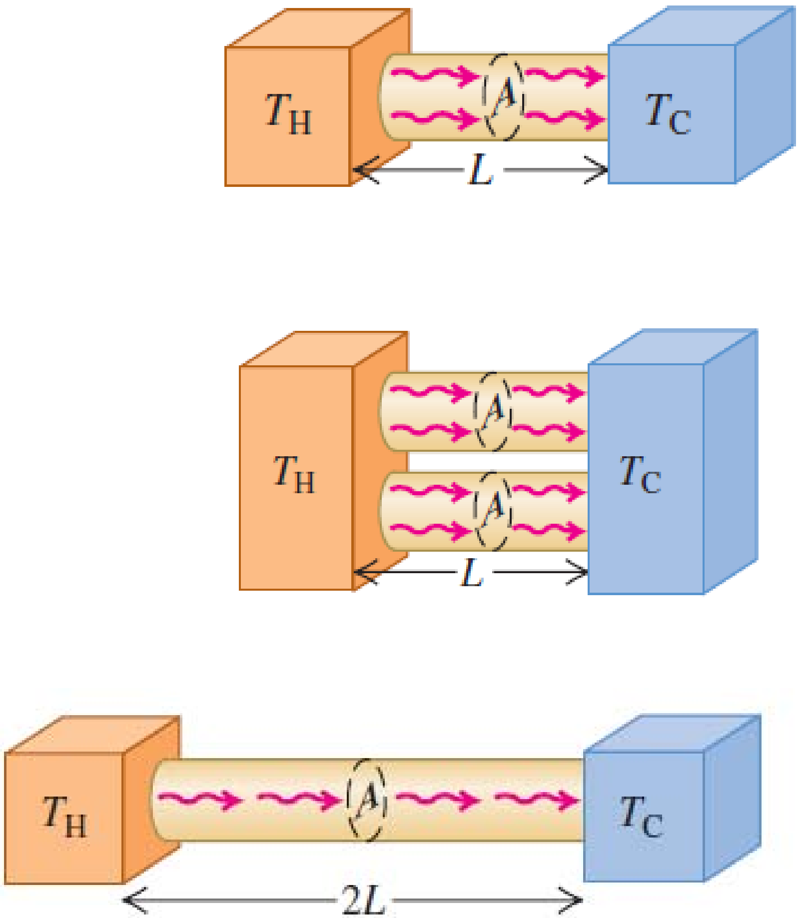
Heat Transport



Heat transfer mechanisms



Heat conduction



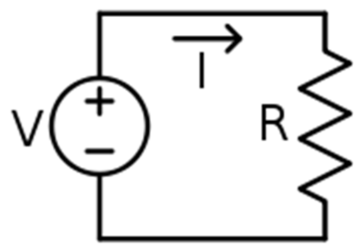
$$H_{cond} = \frac{dQ}{dt} = kA\frac{T_h - T_c}{L}$$

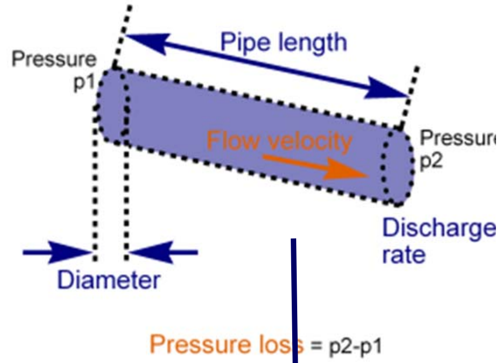
Thermal conductivity

$$H_{cond} = \frac{dQ}{dt} = -kA\frac{dT}{dx}$$

Always in direction
decreasing temperature

Analogies



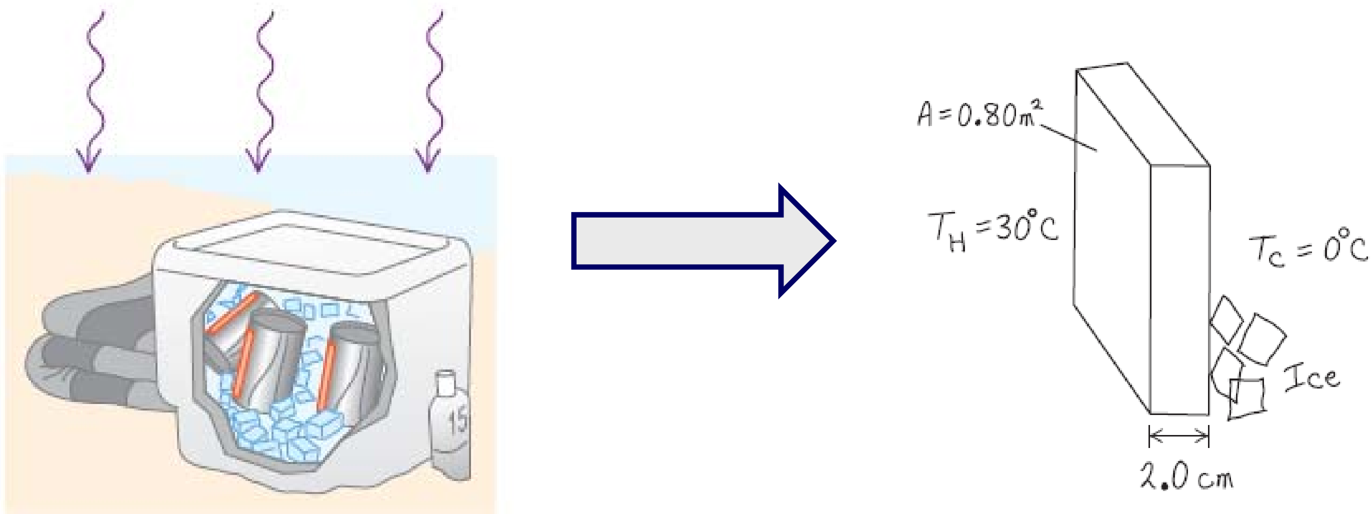


Electrical	Thermal	Fluid
$\boldsymbol{i}$ (current)	$\boldsymbol{\phi}$ (heat flux)	$\boldsymbol{q}$ (flow)
$\boldsymbol{v}$ (voltage)	$\boldsymbol{T, \theta}$ (temper-ature)	$\boldsymbol{p}$ (pressure)
$v = i\boldsymbol{R}$	$\theta = \phi\boldsymbol{R}$	$p = q\boldsymbol{R}$

Thermal conductivity (W/mK)

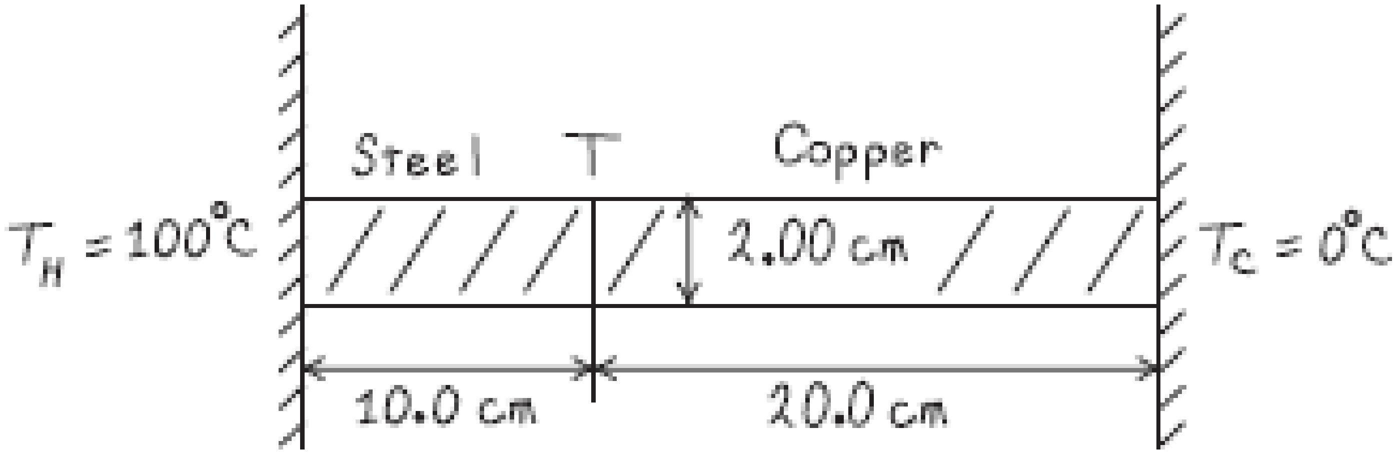
Substance	k (W/m · K)
Metals	
Aluminum	205.0
Brass	109.0
Copper	385.0
Lead	34.7
Mercury	8.3
Silver	406.0
Steel	50.2
Solids (representative values)	
Brick, insulating	0.15
Brick, red	0.6
Concrete	0.8
Cork	0.04
Felt	0.04
Fiberglass	0.04
Glass	0.8
Ice	1.6
Rock wool	0.04
Styrofoam	0.027
Wood	0.12–0.04
Gases	
Air	0.024
Argon	0.016
Helium	0.14
Hydrogen	0.14
Oxygen	0.023

A Styrofoam cooler, total wall area 0.8m^2, wall thickness 2.0 cm.
Filled with ice, water, and cans of Omni-Cola
What is the heat flow if the temperature of the outside wall 30^{o}C?
How much ice melts te of heatflow into the coolin 3 hours?



$$\mathrm{H}_{cond} = kA\frac{T_h - T_c}{L} = 0.027\,0.8\,\frac{30-0}{0.02} = 32.4W$$

$$\mathrm{m} = \frac{Q}{L_{ice}} = \frac{H_{cond}t}{L_{ice}} = \frac{32.4\,3\,3600-0}{3.34\,10^5} = 1kg$$



$$H_s = H_{cu} \qquad H_s = k_s A \frac{T_h - T}{L_s} = k_{cu} A \frac{T - T_c}{L_s} = H_{cu}$$

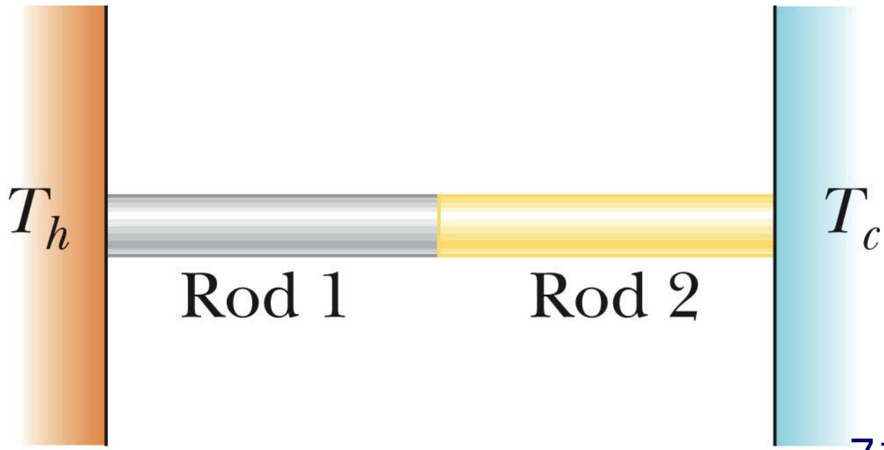
$$T = \frac{\frac{k_s}{L_s} T_h + \frac{k_{cu}}{L_{cu}} T_c}{\left(\frac{k_s}{L_s} + \frac{k_{cu}}{L_{cu}} \right)}$$

Thermal resistance

- Thermal conductivity $\mathrm{H}_{cond} = \dfrac{dQ}{dt} = kA\dfrac{T_h - T_c}{L}$
- Thermal resistance: $R = \dfrac{L}{k}$ $\quad \mathrm{H}_{cond} = A\dfrac{T_h - T_c}{R}$
- Conduction through a composite rod:

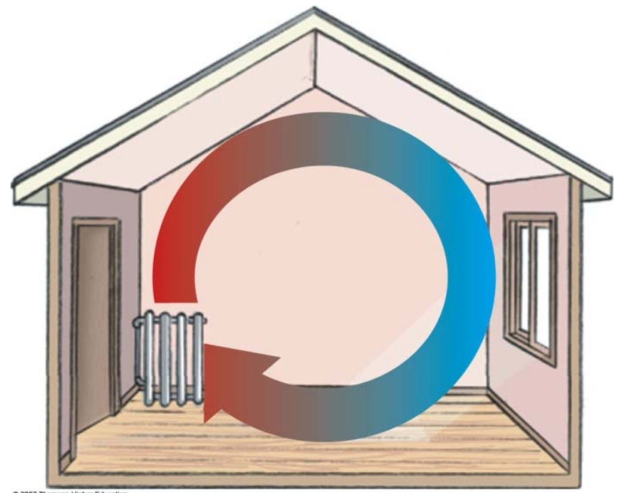
$$\mathcal{H}_{cond} = \frac{A(T_h - T_c)}{L_1/k_1 + L_2/k_2}$$

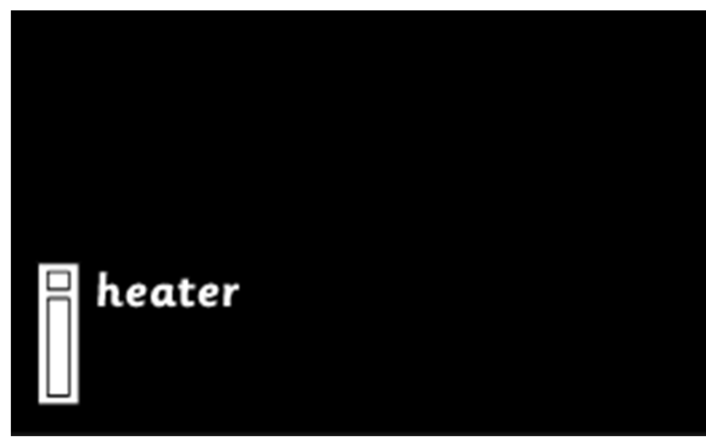
$$= \frac{A(T_h - T_c)}{R_1 + R_2}$$



Convection

Convection: is the transfer of heat by mass motion of a fluid from one region of space to another (complex)





Convection

Windchill factor

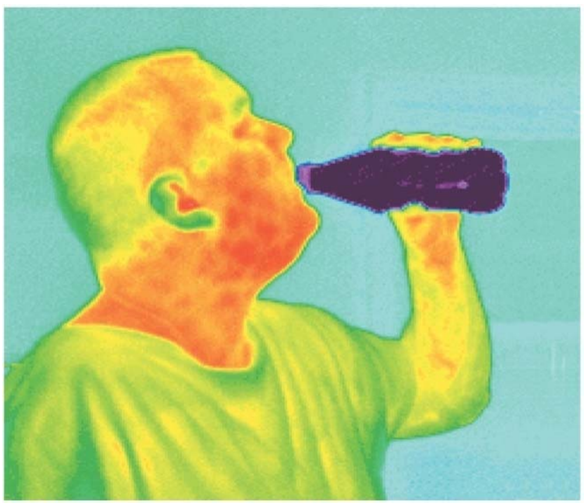
Wind Speed (km/hr)	Air Temperature (Celsius)																
	0	-1	-2	-3	-4	-5	-10	-15	-20	-25	-30	-35	-40	-45	-50	-55	-60
6	-2	-3	-4	-5	-7	-8	-14	-19	-25	-31	-37	-42	-48	-54	-60	-65	-71
8	-3	-4	-5	-6	-7	-9	-14	-20	-26	-32	-38	-44	-50	-56	-61	-67	-73
10	-3	-5	-6	-7	-8	-9	-15	-21	-27	-33	-39	-45	-51	-57	-63	-69	-75
15	-4	-6	-7	-8	-9	-11	-17	-23	-29	-35	-41	-48	-54	-60	-66	-72	-78
20	-5	-7	-8	-9	-10	-12	-18	-24	-30	-37	-43	-49	-56	-62	-68	-75	-81
25	-6	-7	-8	-10	-11	-12	-19	-25	-32	-38	-44	-51	-57	-64	-70	-77	-83
30	-6	-8	-9	-10	-12	-13	-20	-26	-33	-39	-46	-52	-59	-65	-72	-78	-85
35	-7	-8	-10	-11	-12	-14	-20	-27	-33	-40	-47	-53	-60	-66	-73	-80	-86
40	-7	-9	-10	-11	-13	-14	-21	-27	-34	-41	-48	-54	-61	-68	-74	-81	-88
45	-8	-9	-10	-12	-13	-15	-21	-28	-35	-42	-48	-55	-62	-69	-75	-82	-89
50	-8	-10	-11	-12	-14	-15	-22	-29	-35	-42	-49	-56	-63	-69	-76	-83	-90
55	-8	-10	-11	-13	-14	-15	-22	-29	-36	-43	-50	-57	-63	-70	-77	-84	-91
60	-9	-10	-12	-13	-14	-16	-23	-30	-36	-43	-50	-57	-64	-71	-78	-85	-92
65	-9	-10	-12	-13	-15	-16	-23	-30	-37	-44	-51	-58	-65	-72	-79	-86	-93
70	-9	-11	-12	-14	-15	-16	-23	-30	-37	-44	-51	-58	-65	-72	-80	-87	-94
75	-10	-11	-12	-14	-15	-17	-24	-31	-38	-45	-52	-59	-66	-73	-80	-87	-94
80	-10	-11	-13	-14	-15	-17	-24	-31	-38	-45	-52	-60	-67	-74	-81	-88	-95
85	-10	-11	-13	-14	-16	-17	-24	-31	-39	-46	-53	-60	-67	-74	-81	-89	-96
90	-10	-12	-13	-15	-16	-17	-25	-32	-39	-46	-53	-61	-68	-75	-82	-89	-96
95	-10	-12	-13	-15	-16	-18	-25	-32	-39	-47	-54	-61	-68	-75	-83	-90	-97
100	-11	-12	-14	-15	-16	-18	-25	-32	-40	-47	-54	-61	-69	-76	-83	-90	-98
105	-11	-12	-14	-15	-17	-18	-25	-33	-40	-47	-55	-62	-69	-76	-84	-91	-98
110	-11	-12	-14	-15	-17	-18	-26	-33	-40	-48	-55	-62	-70	-77	-84	-91	-99

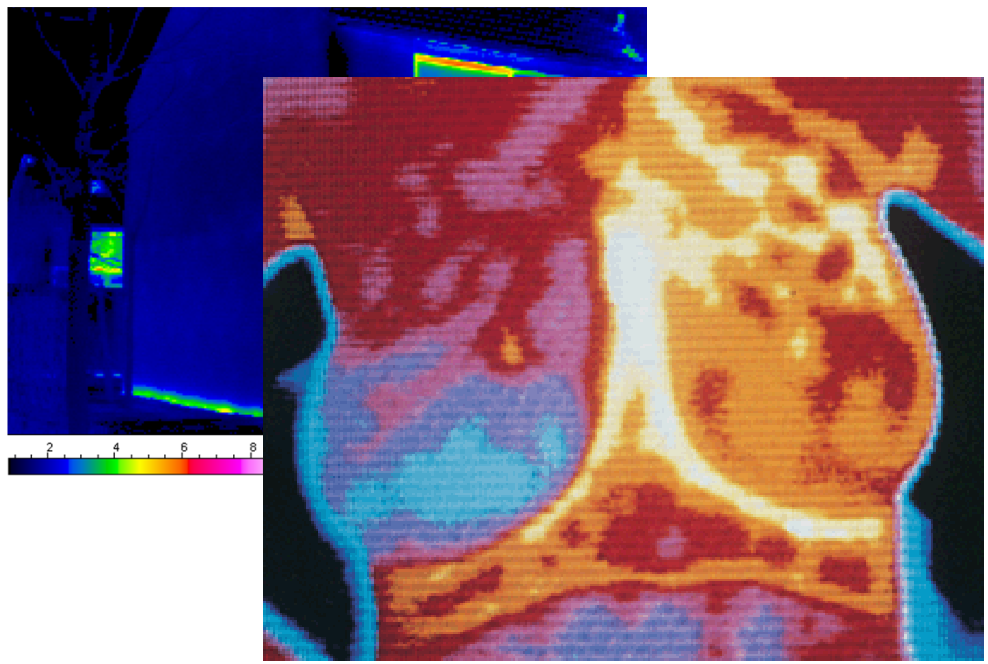
0 to -10 Low | -10 to -25 Moderate | -25 to - 45 Cold | -45 to -59 Extreme | -60 Plus very Extreme

Radiation

All objects give off energy in the form of radiation, as electromagnetic waves – infrared, visible light, ultraviolet – which, unlike conduction and convection, can transport heat through a vacuum.

Best known: infrared





Right breast in this thermograph has an invasive carcinoma (cancer)

Radiation

Emissivity (0-1)

$$H_{rad} = \sigma e A T^4$$

$$\sigma = 5.67 \times 10^{-8} W / m^2 \cdot K^4$$

Stefan-Boltzmann constant

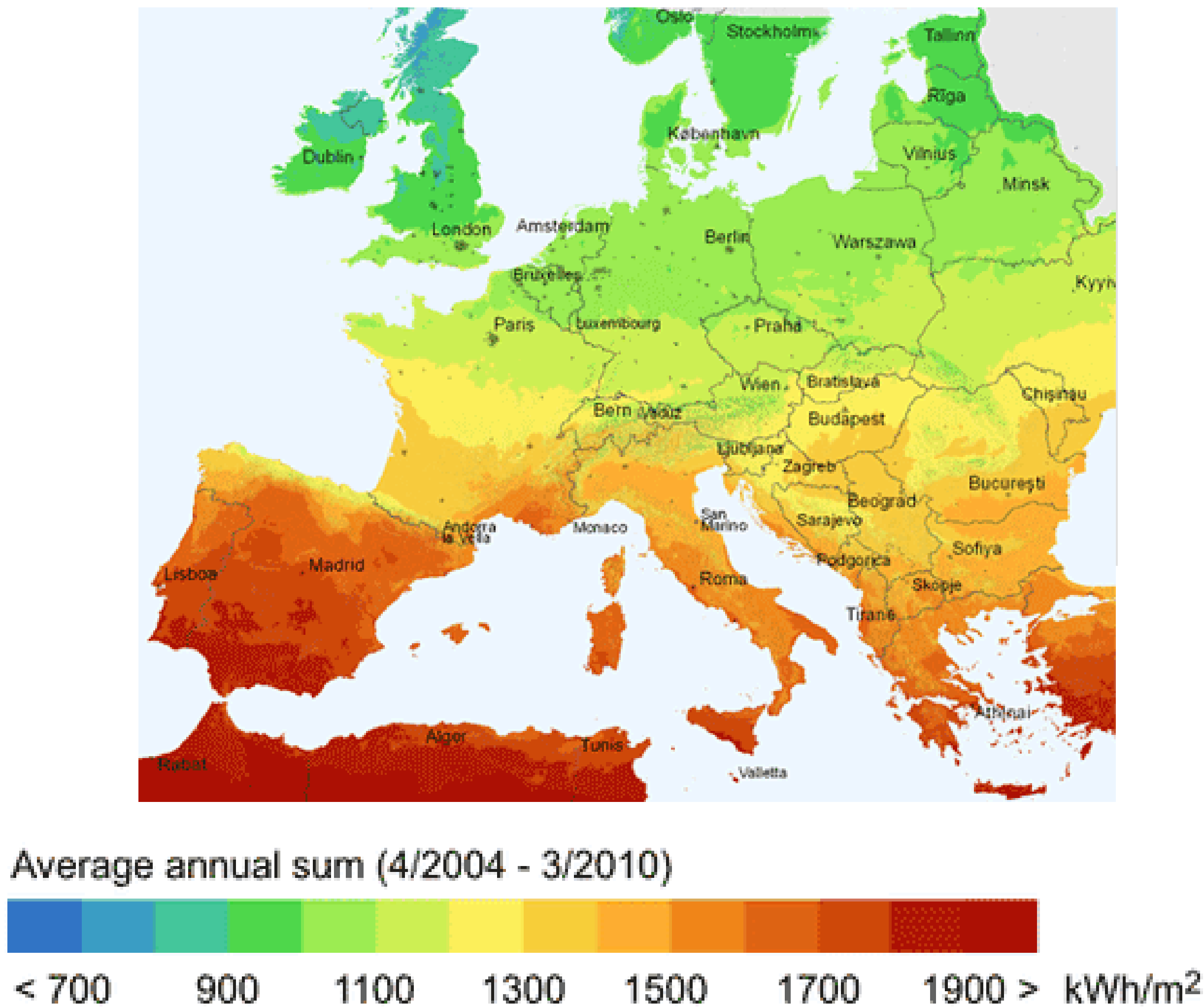
Josef Stefan
(1835-1893)

$$H_{abs} = \sigma e A T_{env}^4$$

$$H_{net} = H_{abs} - H_{rad}$$

$$= \sigma e A (T_{env}^4 - T^4)$$

yearly sun heat flux kWh/m^2



Radiation: example

Athlete is sitting in dark room of 15°C. Estimate the heat loss by radiation assuming 34°C and e=0.7 and area not in contact chair 1.5m^2

$$\text{H} = \frac{dQ}{dt} = \sigma e A(T_{env}^4 - T^4) = 0.7\sigma(307^4 - 288^4) = 120W$$

Quiz

Some management gurus claim that they can let people walk on hot coals because of their motivational abilities. What physical explanation(s) would also be suitable?

1. Heat transport due to conduction is limited since coal and embers are a very poor heat conductors
2. Heat radiation to the feet is very limited due to short duration of the walk
3. Convection doesn’t play a big role here
4. All of the above

Summary

Temperature and temperature scales: Two bodies in thermal equilibrium must have the same temperature. A conducting material between two bodies permits them to interact and come to thermal equilibrium; an insulating material impedes this interaction.

The Celsius and Fahrenheit temperature scales are based on the freezing ($0°C = 32°F$) and boiling ($100°C = 212°F$) temperatures of water. One Celsius degree equals $\frac{9}{5}$ Fahrenheit degrees. (See Example 17.1.)

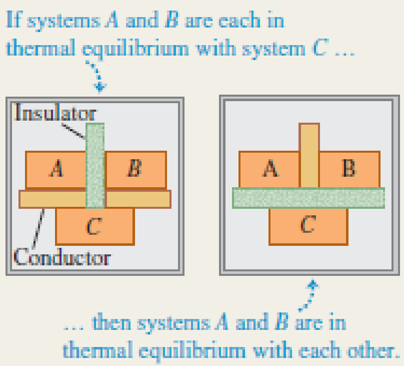
The Kelvin scale has its zero at the extrapolated zero-pressure temperature for a gas thermometer, $-273.15°C = 0$ K. In the gas-thermometer scale, the ratio of two temperatures T_1 and T_2 is defined to be equal to the ratio of the two corresponding gas-thermometer pressures p_1 and p_2.

$$T_F = \tfrac{9}{5}T_C + 32° \qquad (17.1)$$

$$T_C = \tfrac{5}{9}(T_F - 32°) \qquad (17.2)$$

$$T_K = T_C + 273.15 \qquad (17.3)$$

$$\frac{T_2}{T_1} = \frac{p_2}{p_1} \qquad (17.4)$$



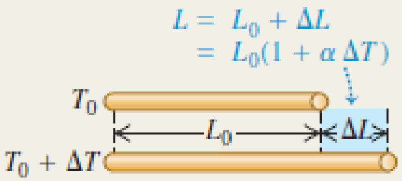
Thermal expansion and thermal stress: A temperature change ΔT causes a change in any linear dimension L_0 of a solid body. The change ΔL is approximately proportional to L_0 and ΔT. Similarly, a temperature change causes a change ΔV in the volume V_0 of any solid or liquid; ΔV is approximately proportional to V_0 and ΔT. The quantities α and β are the coefficients of linear expansion and volume expansion, respectively. For solids, $\beta = 3\alpha$. (See Examples 17.2 and 17.3.)

When a material is cooled or heated and held so it cannot contract or expand, it is under a tensile stress F/A. (See Example 17.4.)

$$\Delta L = \alpha L_0 \, \Delta T \qquad (17.6)$$

$$\Delta V = \beta V_0 \, \Delta T \qquad (17.8)$$

$$\frac{F}{A} = -Y\alpha \, \Delta T \qquad (17.12)$$



Heat, phase changes, and calorimetry: Heat is energy in transit from one body to another as a result of a temperature difference. Equations (17.13) and (17.18) give the quantity of heat Q required to cause a temperature change ΔT in a quantity of material with mass m and specific heat c (alternatively, with number of moles n and molar heat capacity $C = Mc$, where M is the molar mass and $m = nM$). When heat is added to a body, Q is positive; when it is removed, Q is negative. (See Examples 17.5 and 17.6.)

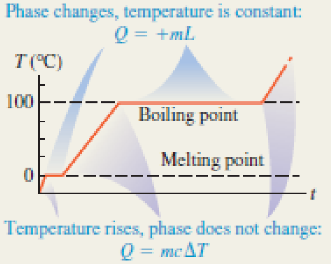
To change a mass m of a material to a different phase at the same temperature (such as liquid to vapor), a quantity of heat given by Eq. (17.20) must be added or subtracted. Here L is the heat of fusion, vaporization, or sublimation.

In an isolated system whose parts interact by heat exchange, the algebraic sum of the Q's for all parts of the system must be zero. (See Examples 17.7–17.10.)

$$Q = mc\,\Delta T \qquad (17.13)$$

$$Q = nC\,\Delta T \qquad (17.18)$$

$$Q = \pm mL \qquad (17.20)$$



Conduction, convection, and radiation: Conduction is the transfer of heat within materials without bulk motion of the materials. The heat current H depends on the area A through which the heat flows, the length L of the heat-flow path, the temperature difference $(T_H - T_C)$, and the thermal conductivity k of the material. (See Examples 17.11–17.13.)

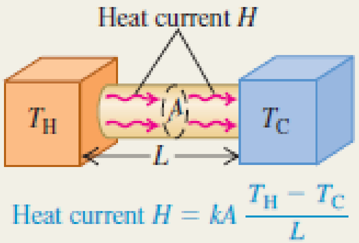
Convection is a complex heat-transfer process that involves mass motion from one region to another.

Radiation is energy transfer through electromagnetic radiation. The radiation heat current H depends on the surface area A, the emissivity e of the surface (a pure number between 0 and 1), and the Kelvin temperature T. Here σ is the Stefan–Boltzmann constant. The *net* radiation heat current H_{net} from a body at temperature T to its surroundings at temperature T_s depends on both T and T_s. (See Examples 17.14 and 17.15.)

$$H = \frac{dQ}{dt} = kA\frac{T_H - T_C}{L} \qquad (17.21)$$

$$H = Ae\sigma T^4 \qquad (17.25)$$

$$H_{net} = Ae\sigma(T^4 - T_s^4) \qquad (17.26)$$



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