Reading Quiz

We observe in the winter that the top of lakes freeze first. Which of the statements below is most true?

A. Fish swimming in the lakes stirs up the water and keeps the temperature of the water below the surface above freezing.
B. The air is colder than the ground, so the top surface of the water freezes first.
C. Density of water is greatest at 4^0C, so water freezing at lower temperatures will rise to surface because of lower densities.
D. The water at the surface of the lake radiates energy away, which makes the water cooler.

Temperature

Thermal equilibrium: pour cold water into a bucket of hot water. After a while, the water is lukewarm.

Temperature characterizes the entire system.

Two systems in thermal equilibrium with a 3rd system are in thermal equilibrium with each other. Called the 0th Law of Thermodynamics

Do experiment with water in Styrofoam cups (3).

Do experiment with wood and metal.
    put in refrigerator before

Thermal reservoir
    Add ice to swimming pool.
    Result - no noticeable change in temperature.
We call this a thermal reservoir or heat bath.

Do thermal effects on solid and gaseous systems (LN_2) demos.

How do we measure temperature?
not so easy.

Criteria:

1) Small effect on surroundings.
2) Good thermal contact.
3) Easily read and reproducible.
4) Special points (like melting ice and boiling water) for calibration.

Constant volume thermometers are useful in determining temperature scales.

Ideal gas: $pV = nRT$
for constant V,n we have $p = (\text{constant})T = CT$

Lab experiment

When $p \to 0$, we believe all motion stops. In next chapter you will see that this means $T \to 0$.

Another good point for temperature scale is the triple point of water. T = 273.16 K

Show transparency of water phases.

For constant volume, $T = 273.16\ \mathrm{K}\left(\frac{p}{p_{tr}}\right)$

Other scales: $0.01^0\mathrm{C}$, $32.02^0\mathrm{F}$

Let's define other temperature scales:

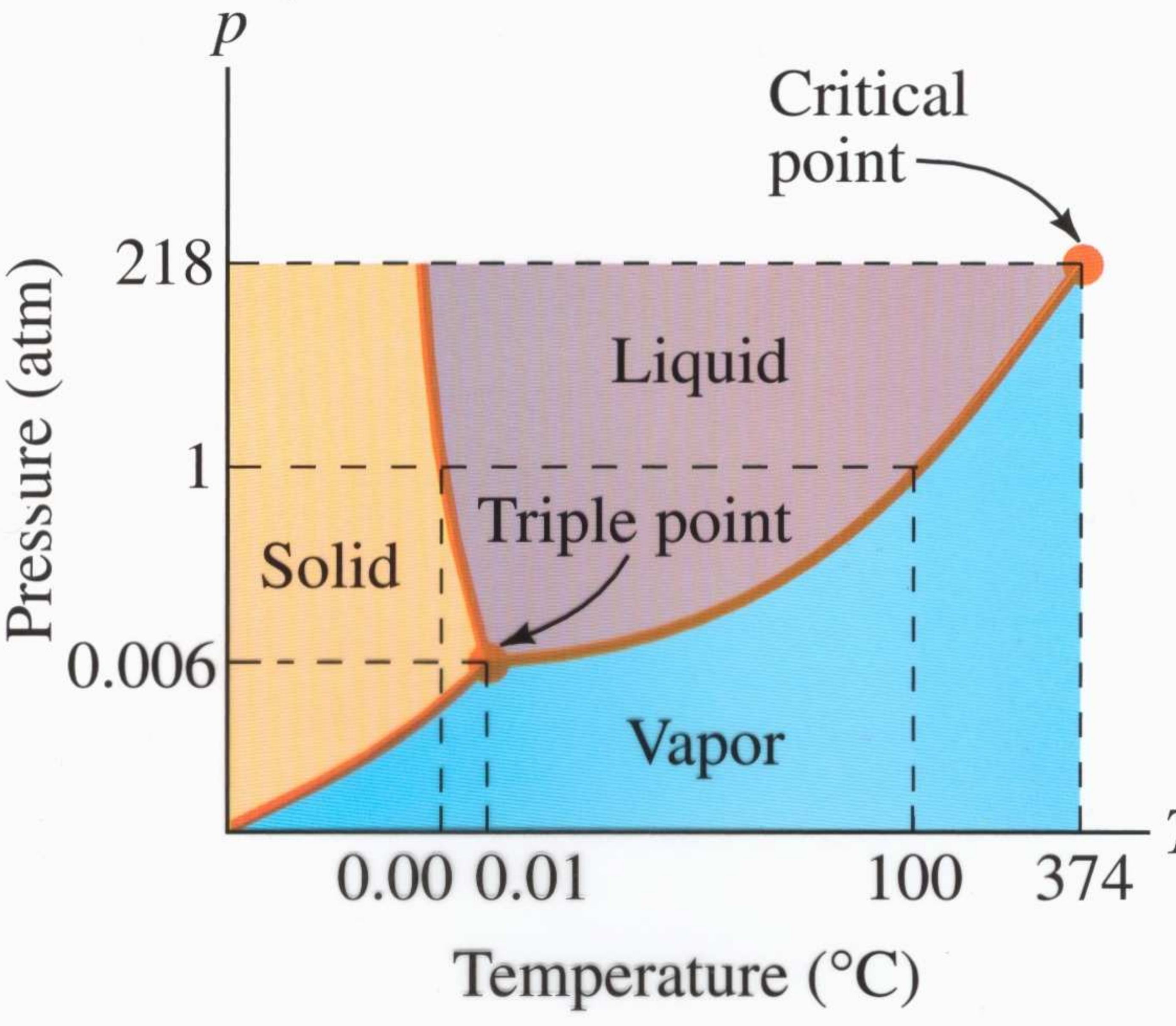
Celsius: $t_C = 0^0\mathrm{C}$ (ice point of water, 1 atm)
$100^0\mathrm{C}$ (boiling point, 1 atm)
$t_\mathrm{C}(\text{in }^0\mathrm{C}) = T - 273.15$

Fahrenheit: $t_\mathrm{F} = 32^0\mathrm{F}$ ice point
$212^0\mathrm{F}$ boiling point

$$t_\mathrm{F}(\text{in }^0\mathrm{F}) = \frac{9}{5}T - 459.67$$

Show transparency for temperatures.

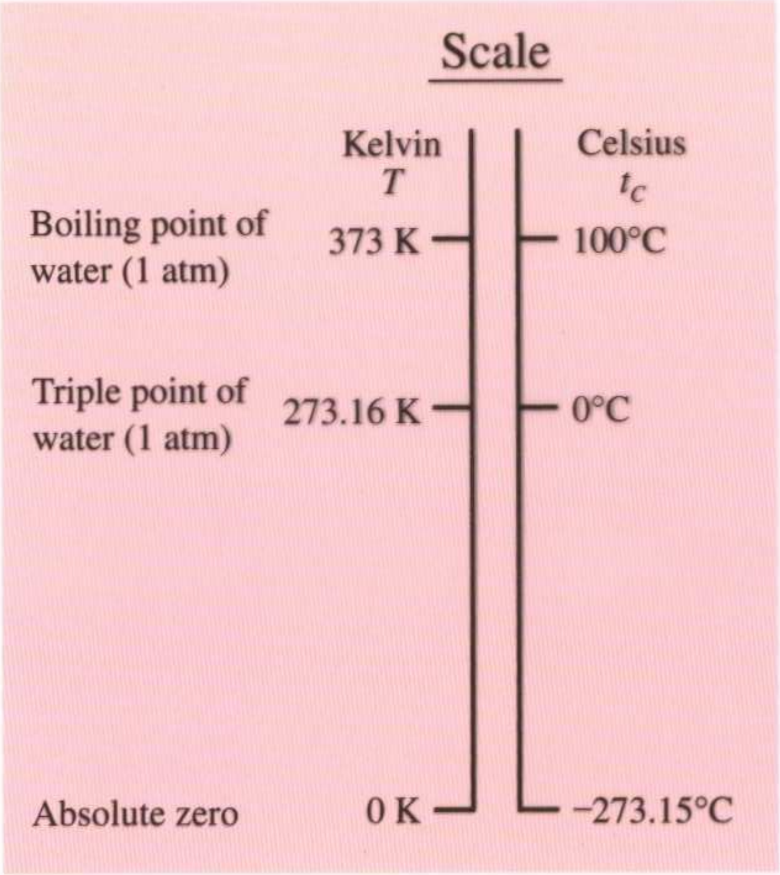
Figure 17-9 Phase diagram for water

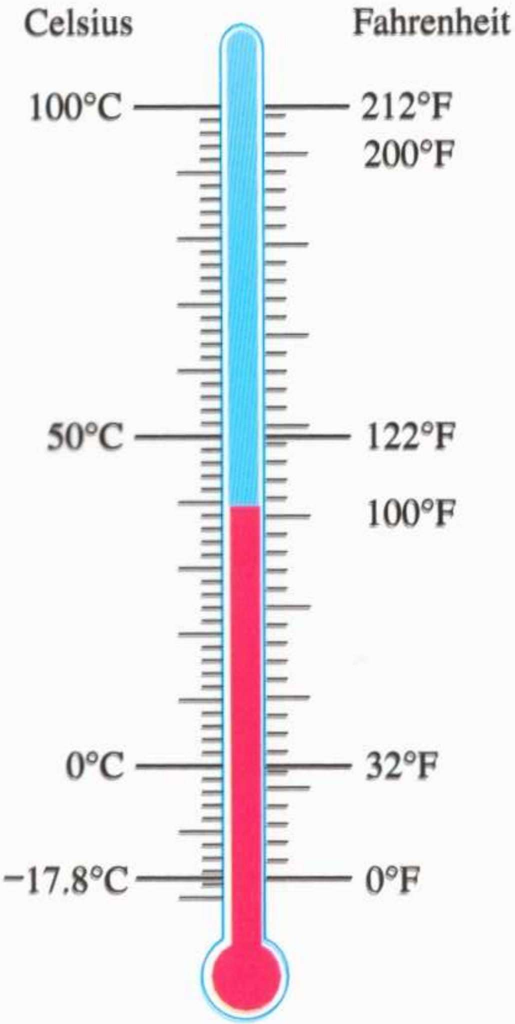


PHYSICS FOR SCIENTISTS AND ENGINEERS 2/E
by Fishbane/Gasiorowicz/Thornton

A Simon & Schuster/Viacom Company
Upper Saddle River, New Jersey 07458

Figure 17-7 & 17-8 Comparison of temperature scales





Thermal Expansion

Sometimes good - loosening a metal lid
Sometimes bad - teeth fillings must be match to teeth

Roads have expansion joints

Linear expansion $\Delta L = L\alpha\,\Delta T$

Volume expansion $\Delta V = V\beta\,\Delta T$

$$\beta = 3\alpha$$

do thermal expansion demos

Heat Flow and 1^{st} Law of Thermodynamics

Thermodynamic variables p, V, T determine the equation of state of a system.

We want to examine changes in the equation of state as we change thermodynamic variables.

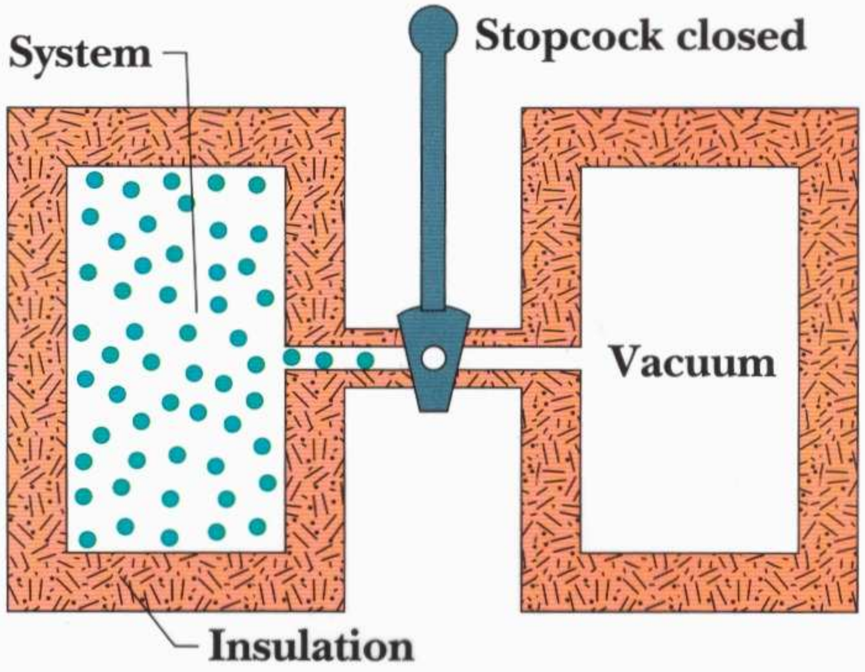
In particular, we want to examine what happens when we add or take away energy from the system.

Reversible processes - a change in which thermal equilibrium is maintained throughout. Such processes go back to the original system when reversed. Example - a piston moving in a cylinder is reversible.

Show transparency of
piston and cylinder.

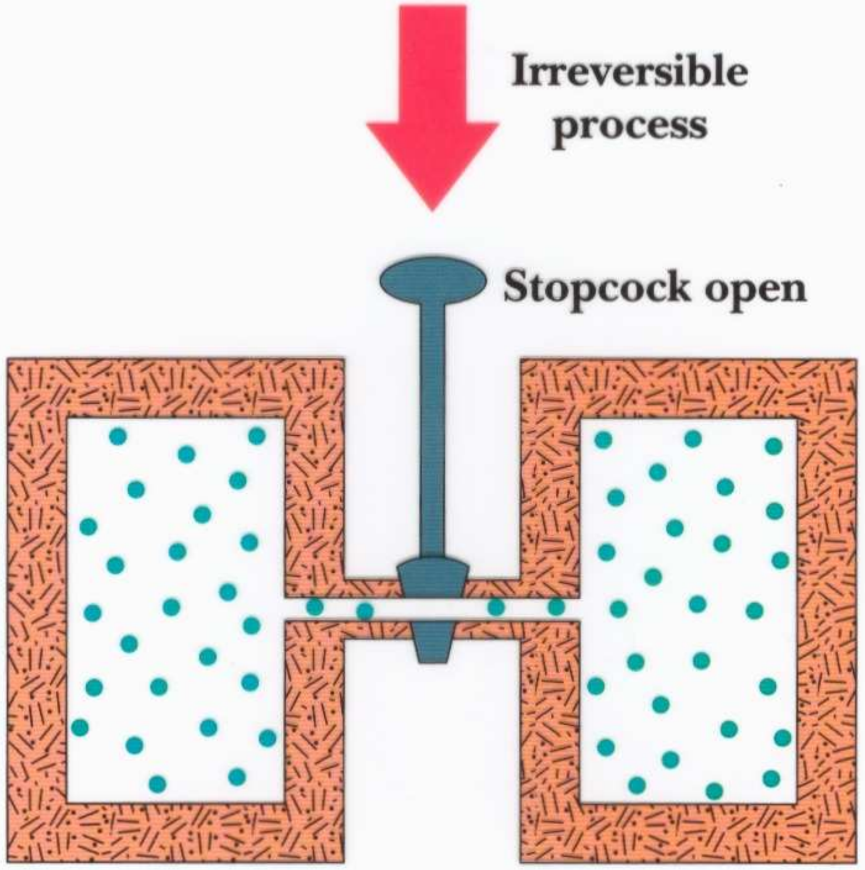
Irreversible processes do not obtain same result when reversed. Example - free expansion of a gas.

Show transparency of free expansion.



ordered

(*a*) Initial state *i*



disordered

(*b*) Final state *f*

FIGURE 21-1

We know that if we heat up a system, then the temperature goes up. We are adding energy.

What do we mean by *heat*?

We will use the symbol Q for heat flow.
Unit of heat flow is the calorie (cal). It is not a SI unit. 1 cal is the energy required to raise 1 g of water from 14.5^0C to 15.5^0C.

1 cal is now defined in terms of the joule.
1 cal = 4.1860 J

food calorie Cal = 1000 cal

Heat flow is a form of energy

Heat flow causes temperature change.

Heat flow has not always been well understood.
Count Rumford (Benjamin Thompson) solved the issue (1798).

We also know that doing work on a system is related to energy.

Is there a relationship between heat flow and work?

Heat Capacity

$$C = \text{heat capacity} = \frac{\Delta Q}{\Delta T}$$

amount of heat flow to raise temperature by 1^0C

$$Q\,(\text{or } \Delta Q) = C\,\Delta T$$

Specific Heat

$$c = \text{specific heat} = \frac{\text{heat capacity}}{\text{mass}} = \frac{\Delta Q}{m\,\Delta T}$$

c is characteristic of the material

$$\boxed{Q\,(\text{or } \Delta Q) = cm\,\Delta T}$$

water has $c = 1$ cal/g·C^0

See Table 19-3, p. 435 for some specific heats.

$Q = Lm$ heat of transformation

L_V is heat of vaporization; 539 cal/g for water
liquid to gas
Heat required to vaporize (boil) 1 g of substance

L_F is heat of fusion; 79.5 cal/g for water
solid to liquid
Heat required to melt 1 g of substance.

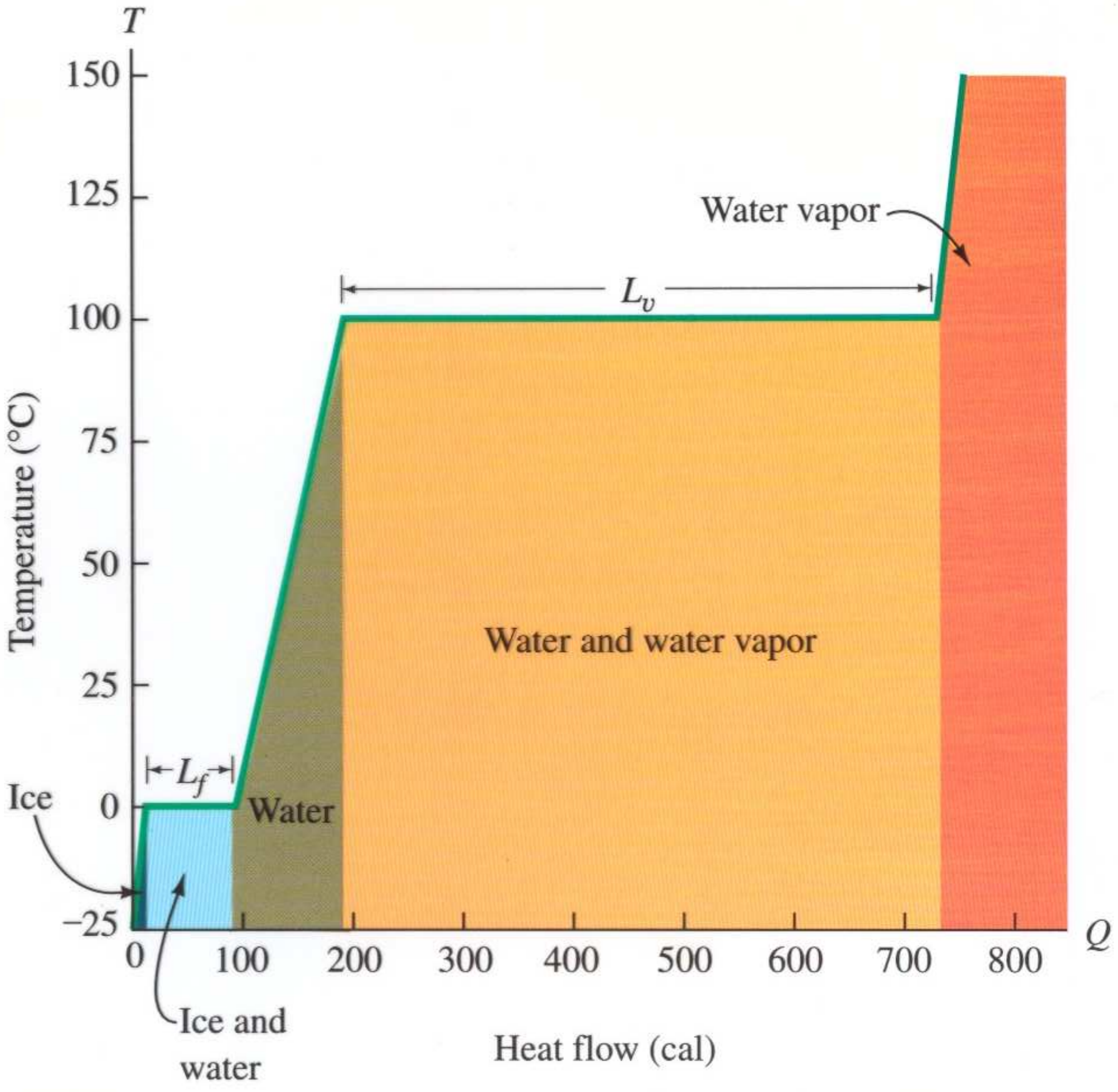
See transparency for water.

Why is heat of vaporization so much larger than the heat of fusion?

Back to heat and work.

James Joule, in 1850, did precise experiments to show the exact relationship. He used falling weights to rotate paddle in an insulated water container.
weights do work
water temperature rises by ΔT

Figure 18-7 **Phase changes and heat flow for water as a function of temperature**



PHYSICS FOR SCIENTISTS AND ENGINEERS 2/E
by Fishbane/Gasiorowicz/Thornton

A Simon & Schuster/Viacom Company
Upper Saddle River, New Jersey 07458

Molar specific heat

$C = mc = nc'$ $\quad\quad c' = \frac{c}{n}$ where n = # moles

c' refers to heat capacity of 1 mol of material

specific heats are in $\frac{\text{cal}}{\text{g} \cdot \text{C}^0}$

molar heat capacities or molar specific heat
is in $\frac{\text{cal}}{\text{mol} \cdot \text{C}^0}$ also in Table 19-3

remember 1 mol = N_A = Avogadro's number
6.02×10^{23} atoms, units

Figuring Physics

States of Matter

Matter can change from one state to another. We speak of *phase changes*.

What happens when we add heat, but get no change in temperature?

FIGURING PHYSICS

A piece of metal and a piece of wood of equal mass and equal temperature are removed from a hot oven and dropped onto blocks of ice. Which will melt more ice before cooling to the ice temperature?

a) The metal.
b) The wood.
c) Both will melt equal amounts of ice.

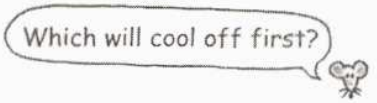
(Answer appears later in this issue)

DOI: 10.1119/1.1535953

FIGURING PHYSICS

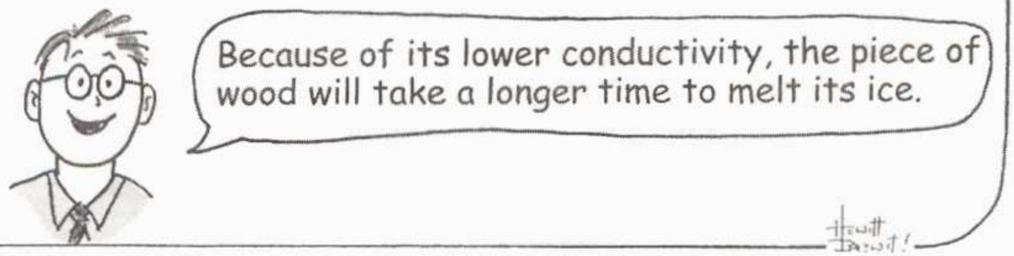
A piece of metal and a piece of wood of equal mass and equal temperature are removed from a hot oven and dropped onto blocks of ice. Which will melt more ice before cooling to the ice temperature?

a) The metal.
b) The wood.
c) Both will melt equal amounts of ice.



Answer: b.

The wood will melt more ice because of its greater specific heat capacity. It releases more energy per degree than the lower-heat-capacity piece of iron.

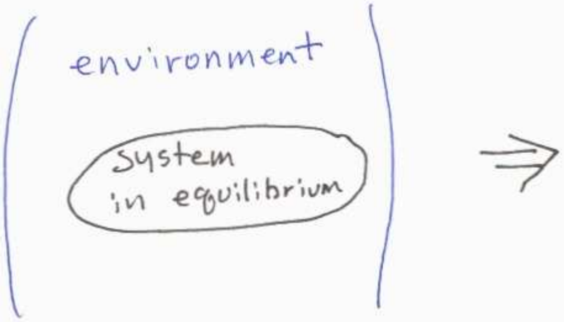


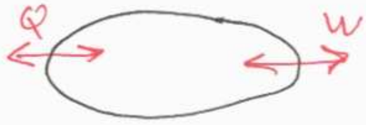
Hewitt Drew it!

We know it takes heat to raise temperature

$$Q = mc\Delta T$$

$$\underset{heat}{1\ \text{cal}} = \underset{work}{4.186\ \text{J}}$$





Q goes in or out of system
W work done on or by the system

Look at piston in cylinder.

Take some mass off cylinder → pressure pushes piston up, moves dS

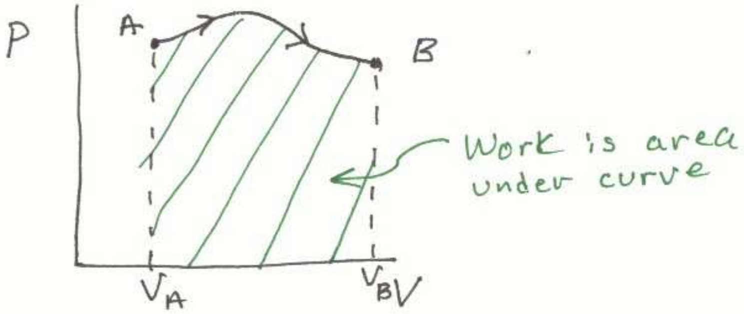
$$dW = \vec{F} \cdot d\vec{s} = (pA)(dS) = p(AdS) = p\,dV$$

$$W = \int dW = \int_{V_i}^{V_f} p\,dV$$

unfortunately, the pressure and temperature may also change while the volume changes, so this integral may not be easy to do. $p = p(V,T)$ through equation of state.

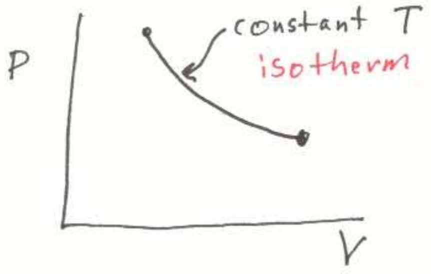
We will look at some easy cases.

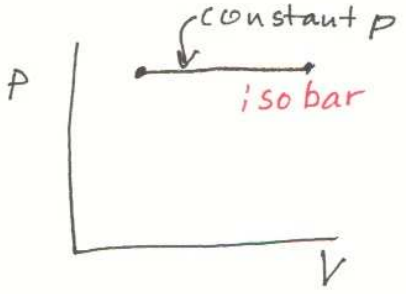
We plot p versus V on a p-V diagram.

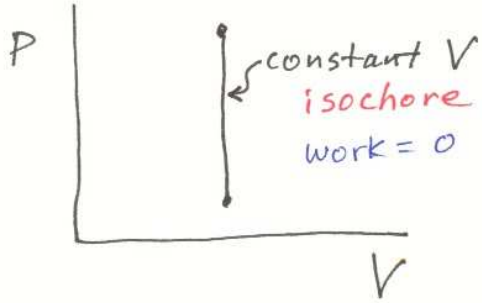


p-V plot showing work

show other pV diagrams







If a system does work while thermally isolated, then no heat can enter or leave system and $dQ = 0$.

Reversible transformations with no heat flow are called *adiabatic* transformations ($dQ = 0$).

For an adiabatic transformation, when a system does work on its surroundings, it must change its own internal (thermal) energy.
In this case, $dU = -dW$ (adiabatic)

$$U_B - U_A = -W_{A\to B} \quad \text{internal energy change}$$

Text uses E_{int} for U.

We already know that heat flow changes the internal energy (raises the temperature)

$$\Delta U = U_B - U_A = +Q_{A\to B}$$

We can combine these results

$\Delta U = Q_{A\to B} - W_{A\to B}$ Conservation of energy
First law of thermodynamics

Figure 18-17 First law of thermodynamics

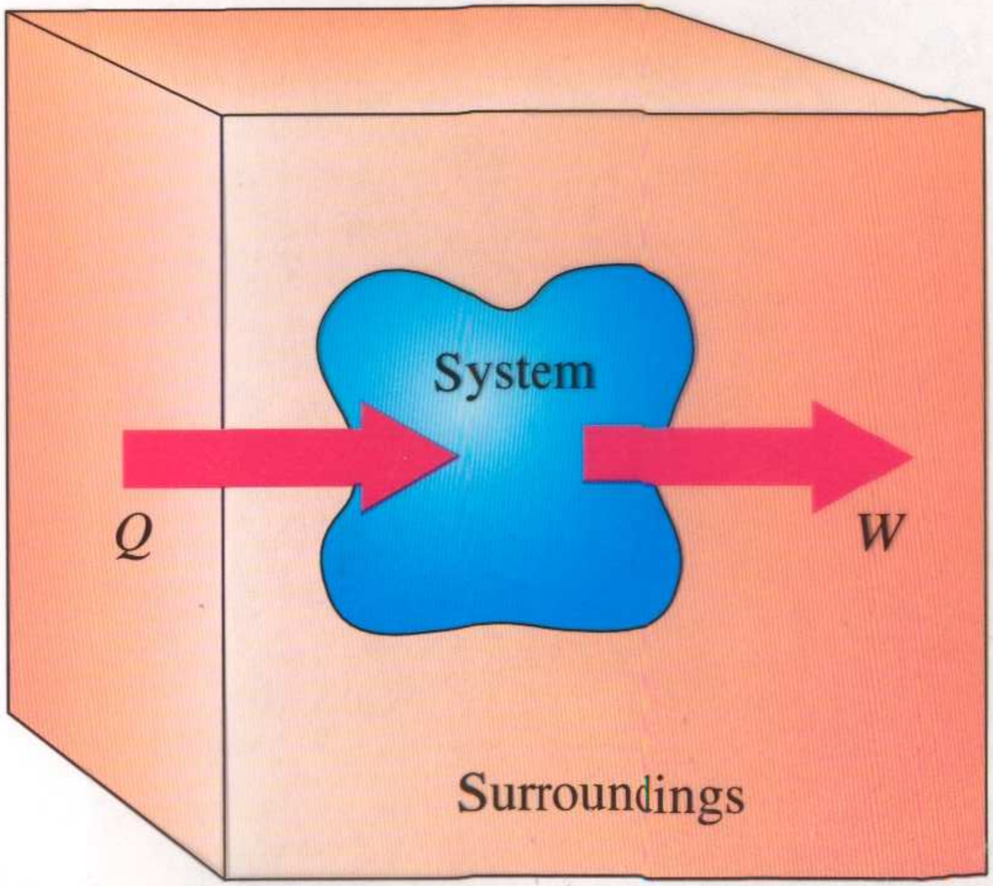
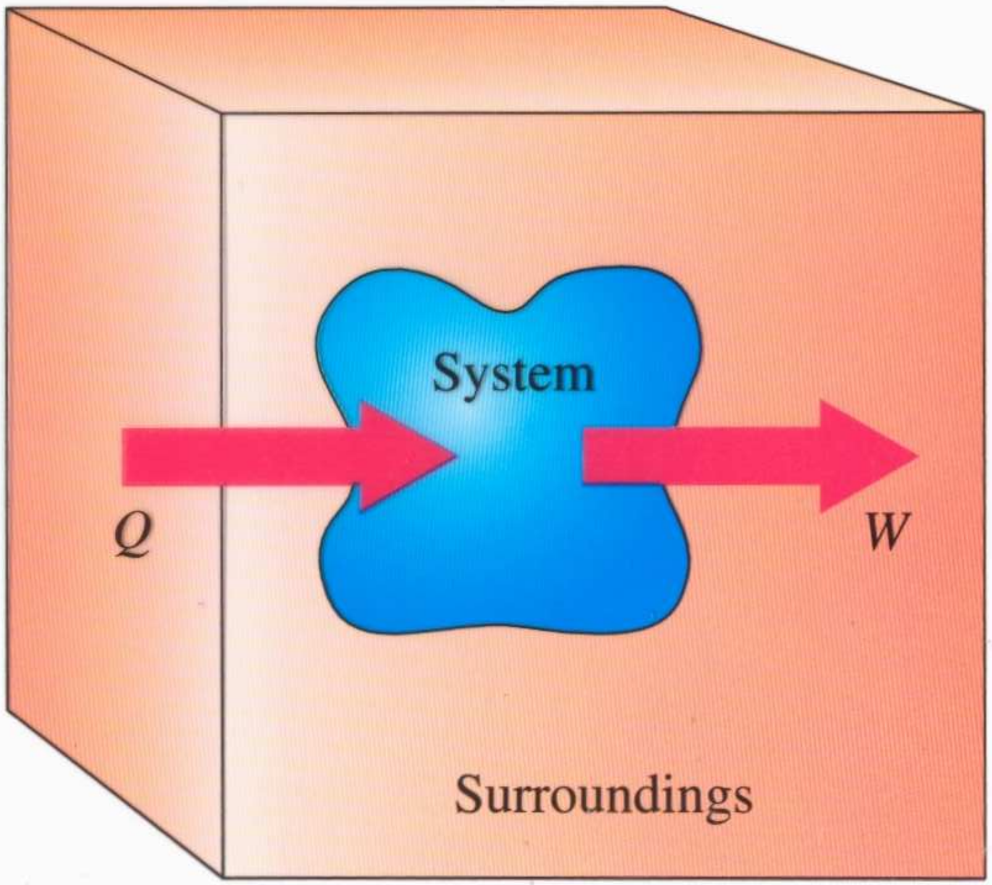


Figure 18-17 First law of thermodynamics



PHYSICS FOR SCIENTISTS AND ENGINEERS 2/E
by Fishbane/Gasiorowicz/Thornton

A Simon & Schuster/Viacom Company
Upper Saddle River, New Jersey 07458

dU doesn't depend on path
$Q = +$ when heat enters the system
$W = +$ when work is done *by* the system

$Q = \Delta U + W$ heat flow added to the system equals change in internal energy and work done by the system.

Now let's complicate matters. Big problem!!

Not everyone uses this convention. Some people think it makes more sense to have
W = + when work is done *on* the system.

Chemists use the latter convention, and generally physicists and engineers use the former one. Unfortunately, the AP test now uses the latter convention as of May 2002.

Physicists don't like it, because then $W = -\int p\, dV$

Look at Table 19-5

First law is important for engines, which are cyclic. Engines come back to initial state, so

$$\Delta U = 0$$

and $$Q_{cycle} = W_{cycle}$$

Heat demos
Heat engine

Heat Transfer

Conduction - moving atoms exchange energy

Convection - hot air (buoyancy) rises
occurs for fluids

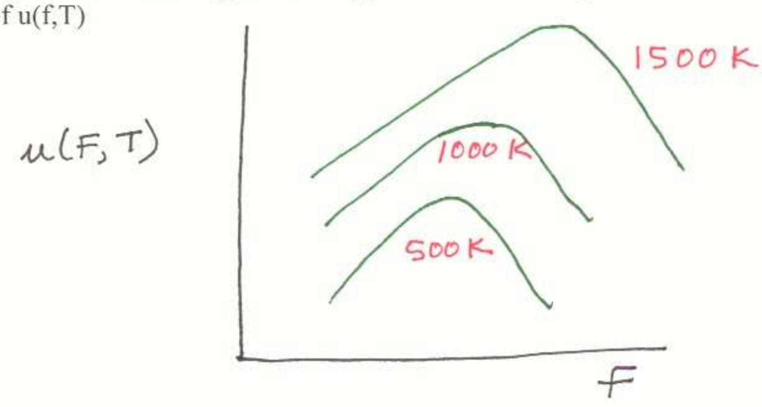
Radiation - electromagnetic waves
Radiation is emitted at all frequencies; we only see visible region of light.

infrared - detected as radiant heat by skin
(ear thermometers)

ultraviolet - can be dangerous to our skin

As temperature goes up, the frequencies go up.

Draw graph of u(f,T)



Stefan-Boltzmann law

the rate at which an object emits energy is

$$P_{rad} = \sigma \varepsilon A T^4$$

where σ is Stefan-Boltzmann constant

ε is *emissivity* (0 to 1, depending on surface)

A is the area

The sun emits light most strongly at $f = 2.0 \times 10^{14}$ Hz. Means T is 6000 K at surface.

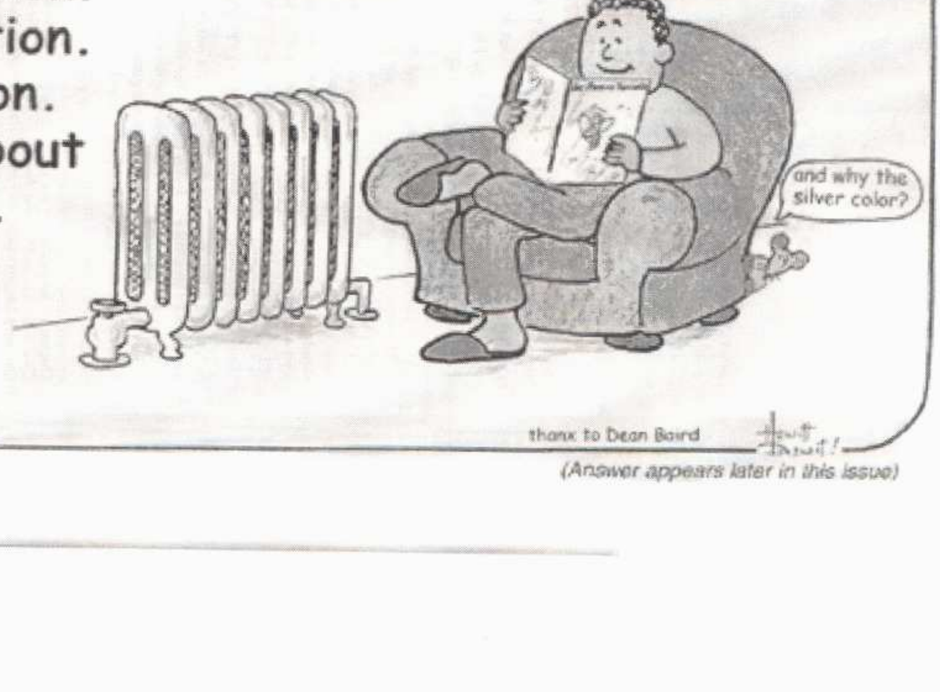
Big Bang theory of universe predicts that the universe has cooled to 3 K given present rate of expansion of universe. That radiation has been detected.

do demos

FIGURING PHYSICS

Hot water/steam radiators are common fixtures that nicely warm the interiors of buildings. These radiators warm a room primarily via

a) conduction.
b) convection.
c) radiation.
d) ...all about equally.



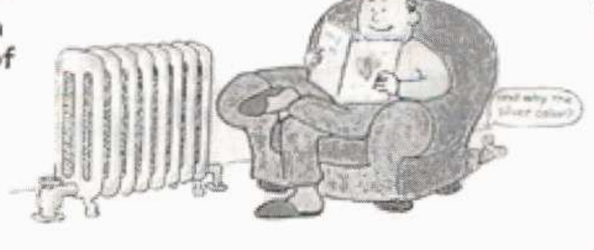
thanx to Dean Baird

(Answer appears later in this issue)

FIGURING PHYSICS

Hot water/steam radiators are common fixtures that nicely warm the interiors of buildings. These radiators warm a room primarily via

- **a) conduction.**
- **b) convection.**
- **c) radiation.**
- **d) ...all about equally.**



Answer: b, by convection.

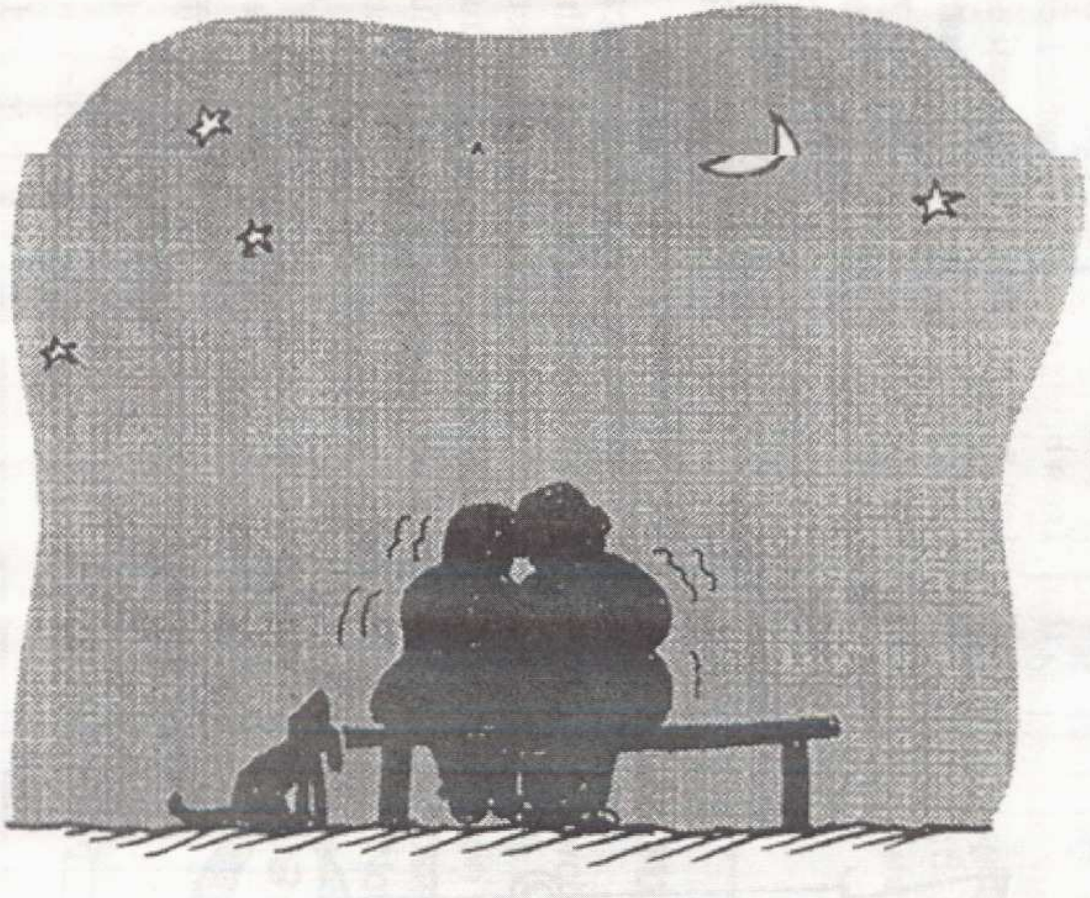
The exposed pipework of the radiator is brought to a high temperature by steam or hot water. Air near the radiator is warmed by conduction. The placement of the radiator in a room allows the newly heated air to rise away from the radiator, drawing cooler air toward it. The radiator warms the cool air and the process continues. This is convection!

Radiators are often painted with highly reflective silverish paint to *reduce* radiation and allow the radiator pipes to become and remain hotter than they otherwise would—increasing their ability to drive convection.

To be comfortably warm in a room, more important than air temperature is the temperature of the walls (which are warmed by *conduction* from convected air). Net *radiation* from your body to the walls is lower for warm walls. So both conduction and radiation play central roles in your comfort. But concerning the radiator itself, convection is the dominant player. Maybe the fixture should be called a "convector?"

Hewitt Drew it!

FIGURING PHYSICS



Why is it significantly colder on a winter night under a clear sky than under a cloudy sky?

Hewitt Drew it!

Figuring Physics

Why is it significantly colder on a winter night under a clear sky than under a cloudy sky?

Answer:

We all know that energy from the glowing sun affects temperature here on earth. Almost as important but less well known, is energy emitted by the " glowing " earth. Like the sun, the earth glows - but only in the infrared. This is *terrestrial radiation* - lower in both frequency and intensity than solar radiation. On a clear night, terrestrial radiation escapes through the atmosphere, which lowers the temperature of the earth's surface and the air near it. But on a cloudy night, much terrestrial radiation is absorbed by the clouds and reradiated back to the earth, countering a nightly lowering of temperature.

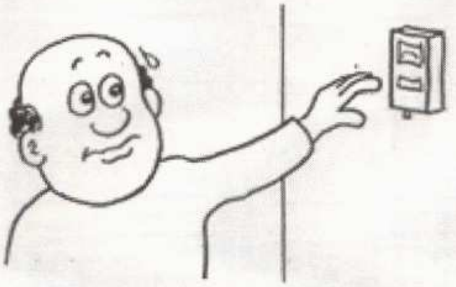
We see why frost forms on a lawn under a clear night sky, but not under a park bench or a grove of trees. The bench and trees reradiate terrestrial radiation to the ground, keeping it warmer.

We also see why fruit growers use smudgepots in orchards on frosty nights. The dark smudgy cloud close to the ground absorbs terrestrial radiation and reradiates it, keeping the air and fruit above freezing. This marks time until sunlight comes to the rescue the following morning!

Hewitt Drew it!

FIGURING PHYSICS

If you wish to save fuel and you're going to leave your cool house for a half hour or so on a very hot day, should you turn your air conditioning thermostat up a bit, turn it off altogether, or let it remain at the cool room temperature you desire?



(answer appears later in this issue)

FIGURING PHYSICS

If you wish to save fuel and you're going to leave your cool house for a half hour or so on a very hot day, should you turn your air conditioning thermostat up a bit, turn it off altogether, or let it remain at the cool room temperature you desire?

Answer:

Turn your air conditioner off altogether and save fuel. The amount of heat that leaks into your house depends on the insulation and the difference in inside and outside temperature, ΔT. In accord with *Newton's law of cooling*, keeping ΔT high consumes more fuel. When you turn your conditioner off you minimize both ΔT and fuel consumption.

Will more fuel be required to re-cool the house when you return than would have been consumed to keep it cool while you were away? Not at all. When you return and turn your conditioner on again, you extract heat at a smaller ΔT. The amount of fuel consumed to bring room temperature to its original cool setting is less than the amount consumed to keep it at the cool setting continuously.

Second Law of Thermodynamics

The first law of thermodynamics is the conservation of energy.

The second law tells us how much work an engine can do.

We cannot convert thermal energy solely to work.

Second law specifies direction thermal energy flows.

Example - ice tea doesn't spontaneously become hot.
First law doesn't forbid it.

Second law has to do with order in systems.

Systems go from order to disorder
(property called entropy)

Let's discuss engines

1) Engines operate in cycles.
2) Engine must have more than 1 heat reservoir.

Our goal is to convert as much heat as possible into work.

Engines are characterized by their efficiency.

Work done in cycle = W

Heat flow from hot reservoir to system = Q_h

$$\varepsilon = \frac{\text{energy we get}}{\text{energy we pay for}} = \frac{|W|}{|Q_h|} \quad \text{thermal efficiency}$$

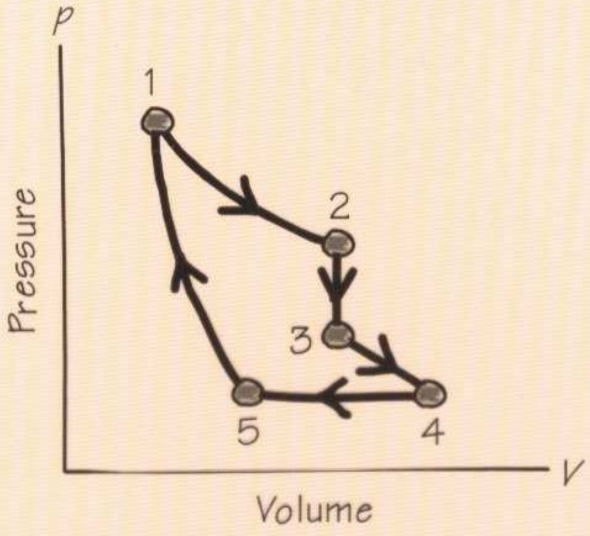
Efficiency cannot be 100% according to 2nd Law.

Look at transparency for determining efficiency.

Figure 20-3 Determining efficiency

Determining Efficiency η

(1) Sketch cycle on p-V diagram



(2) Determine heat flows Q

$1 \rightarrow 2$	isothermal	$Q_1 > 0$
$2 \rightarrow 3$	isochor	$Q_2 < 0$
$3 \rightarrow 4$	adiabatic	$Q_3 = 0$
$4 \rightarrow 5$	isobar	$Q_4 < 0$
$5 \rightarrow 1$	adiabatic	$Q_5 = 0$

(3) Determine W_{net}

W_{net} = area enclosed in p-V diagram

(4) Q_{in} = sum of positive Qs $= Q_1$

(5) $\eta = \dfrac{W_{net}}{Q_{in}}$

PHYSICS FOR SCIENTISTS AND ENGINEERS 2/E
by Fishbane/Gasiorowicz/Thornton

A Simon & Schuster/Viacom Company
Upper Saddle River, New Jersey 07458

The Second Law

1) Kelvin form: No engine (cycle) can convert only thermal energy from a body solely to mechanical work with no other change.

2) Clausius form: No engine can only transfer thermal energy from a colder body to a hotter body with no other change. (something else must happen)

3) No perpetual motion machines are possible.

Do drinking duck demo.

Show transparencies on Carnot cycle.

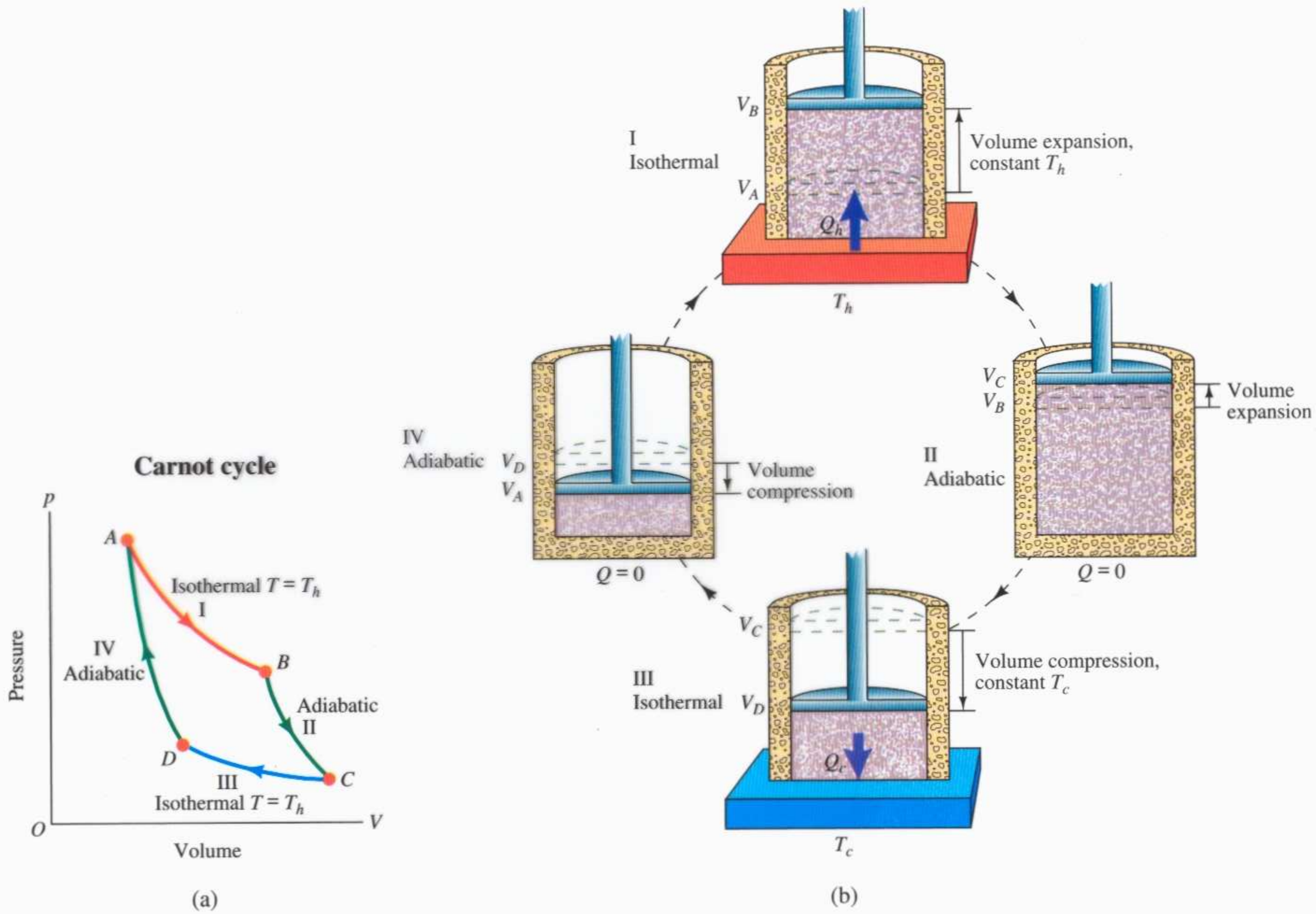
See text. We can show that efficiency for Carnot cycle (engine) is

$$\varepsilon_C = 1 - \frac{|Q_L|}{|Q_H|} = 1 - \frac{T_L}{T_H}$$

No engine is more efficient that a Carnot engine.

Carnot engines can be used to define a temperature scale.

Figure 20-5 T Carnot cycle



(a)

(b)

PHYSICS FOR SCIENTISTS AND ENGINEERS 2/E
by Fishbane/Gasiorowicz/Thornton

A Simon & Schuster/Viacom Company
Upper Saddle River, New Jersey 07458

Figure 20-12 The Carnot cycle operated as a heat pump