Chapter 7: 2nd Law of Thermodynamics (a.k.a. no free lunch, can't break even, the arrow of time, why my coffee gets cold and why the refrigerator has to be plugged in to work, etc.)

Outline of today's class (apart from quizzes):

2nd Law: Another exceptionally broad & important physics principle!
→ Tremendous societal implications
Heat, heating, heat engines
Applications: transportation issues (automobile) & power plants

Leave 7.4 (Entropy) and 7.8 (Resource Use & Exponential Growth) for you to read – please do!

Let’s avoid confusion about “heat”/”heating” & thermal energy:

“Heating”/”to heat” is a verb, something you can do, an E transfer due to a temperature difference – thus similar to work.
A system can’t “have work”, nor can it “have heat”.

Can have: $E_{thermal}$ – a noun, something your soup can have, a form of energy.
Bottom line: don’t say “heat” when you mean $E_{thermal}$, please.

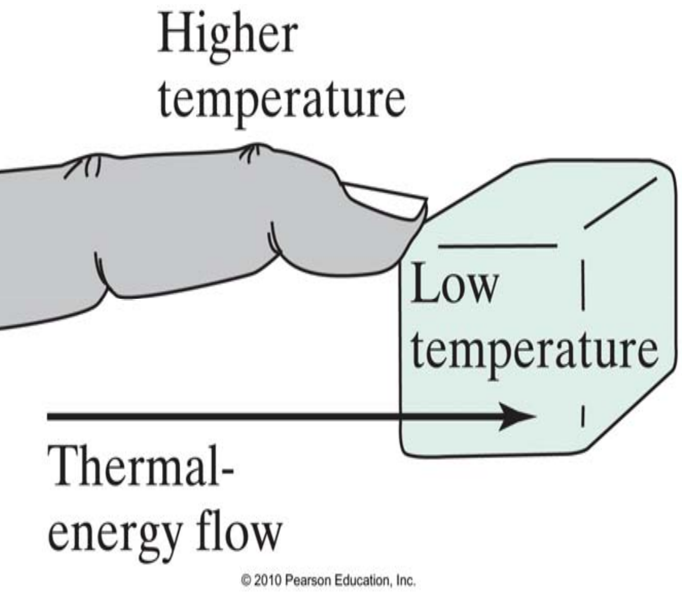
Remember from ch. 2: connection with microscopic E_{kin} of atoms or molecules!

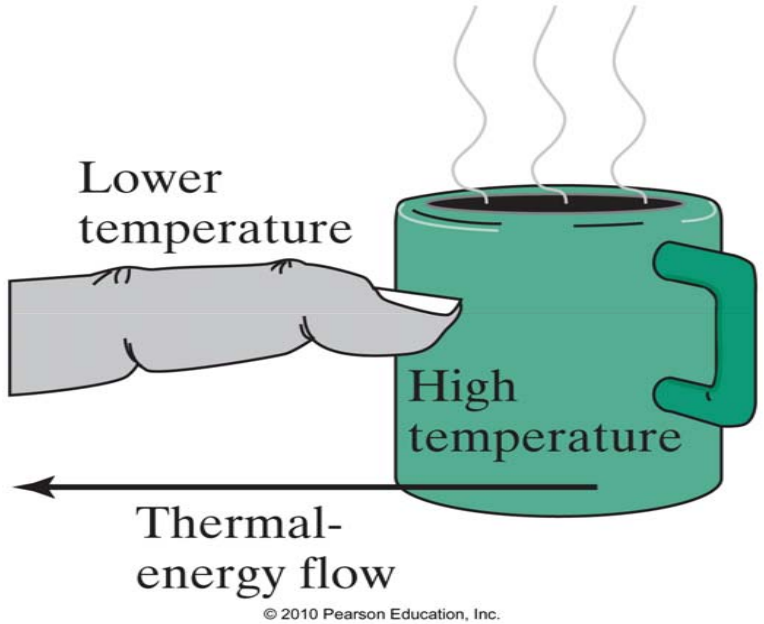
Thermodynamics: study of heat, heating, $E_{thermal}$, and E in general.
In fact the 1st Law of Thermodynamics is simply E conservation, expanded to include $E_{thermal}$ – think about our many examples involving friction, air resistance, etc.

Various formulations of the (very) famous 2nd Law:

A refrigerator won't work unless it's plugged in! ;>)

What the … is this all about?





Familiarize yourself with 3 temp scales: degrees C & F, and Kelvin

→ $E_{thermal}$ always flows spontaneously from hot to cold, never the other way!

Therefore, for $E_{thermal}$ "to flow against the grain", you have to put some energy into the system.

Examples of $E_{nonthermal} \rightarrow E_{thermal}$ everywhere, but give me some examples of the reverse.

Car engine, hot-air balloon, kettle top rattling on a stove,….

$E_{thermal}$ is special: has a "one-wayness" about it – easier to create than to use.

Temperature is a quantitative measure of "warmth", which is not the same as $E_{thermal}$ (different units, obviously).

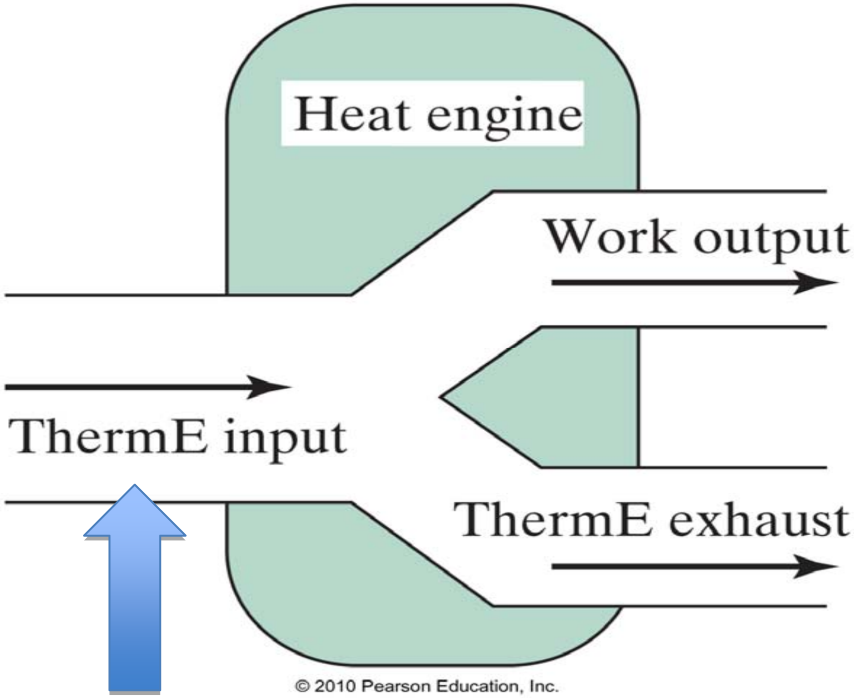
<u>Quiz # 48</u>: Do hotter objects always have more $E_{thermal}$ than colder objects?

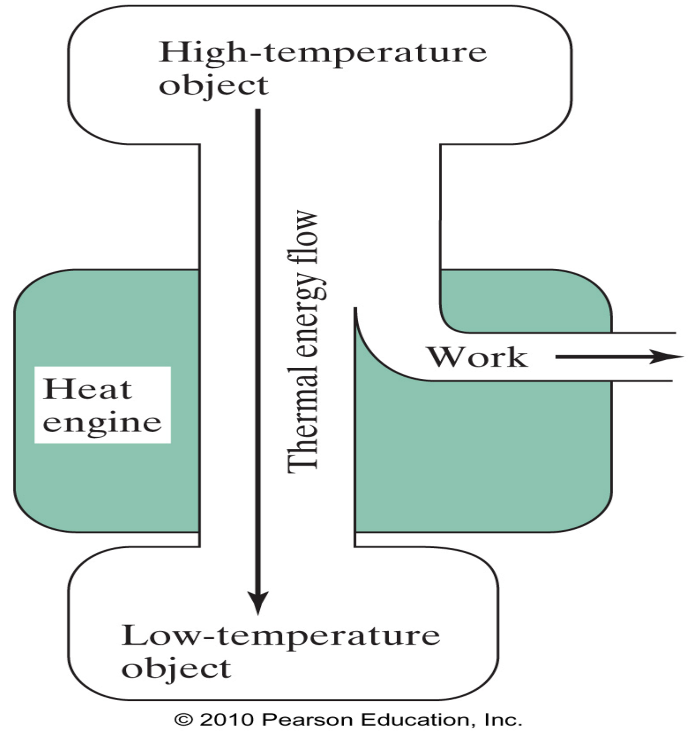
(a) yes (b) no

Returning to the flow of $E_{thermal}$: Why do good windows matter (C.E. 4)?

Because they put up at least some fight against the 2nd Law.

Crucial application of thermodynamics, and one with tremendous societal impact & relevance: <u>Heat Engines</u> – cyclic, converting $E_{thermal} \rightarrow E_{nonthermal}$ (such as mechanical work), BUT *not* with 100% efficiency. Another manifestation of the 2nd Law!





Often from some other E, such as chemical.

<u>Efficiency = (W out / E in) < 100%, always!</u>

The Second Law of Thermodynamics, Stated as the Law of Heat Engines

Any cyclic process that uses thermal energy to do work must also have a thermal energy exhaust. In other words, heat engines are always less than 100% efficient at using thermal energy to do work.

Or: Impossible to build an engine operating on a cycle, whose <u>only</u> effect is to convert $E_{thermal}$ into an equivalent amount of work.

Table 7.1

Heat engine efficiencies. Typical temperatures, best possible efficiencies, and actual efficiencies.

Note the low (max) efficiencies allowed by the 2nd Law → societal impact!!

Engine type	T_{in}(°C)	T_{ex}(°C)	Efficiency (%) Best possible	Efficiency (%) Actual
Transportation				
Gasoline automobile/truck	700	340	37	20
Diesel auto/truck/locomotive	900	340	48	30
Steam locomotive	180	100	20	10
Steam-electric power plants				
Fossil fuel	550	40	60	40
Nuclear fuel	350	40	50	35
Solar powered	225	40	40	30
Ocean-thermal (solar)	25	5	7	???

How to calculate these best possible efficiencies? (footnote 3, p. 139)
Without derivation:

eff. = Work output / $E_{thermal}$ input = $(T_{input} - T_{exhaust}) / T_{input}$

T in K(elvin) ! (degrees C + 273)

So, burning hot & exhausting cool is optimum….but, plenty of practical/engineering/technical limits, unfortunately.

C.E. 16: 100 J of work & 400 J of $E_{thermal}$ exhausted. E_{input} & eff. = ?

$E_{input} = E_{output}^{total} = E_{thermal}^{exhausted}$ + work = 400 J + 100 J = 500 J eff. = useful work / E_{input} = 100 J / 500 J = 20%

Look at C.E. 7 & 9

Quiz # 49: A heat engine's eff. is 30% and its work output 2000 J.
Its input $E_{thermal}$ is
(a) 2 kJ (b) around 6.7 kJ (c) 600 J (d) need temperatures

Quiz # 50: In a solar-powered electricity generating plant steam is heated to 250 degrees C. After passing through the turbines, cooling towers cool the steam to 30 degrees C. This plant's maximum possible efficiency is approximately

(a) 40% (b) 10% (c) 20% (d) 60%

Remember: need T in Kelvin = degrees C + 273!

Follow-on (problem 5): 25%

→ "Co-generation": $E_{thermal}$ in exhaust must not always be totally wasted! (UNM has a co-generation plant.)

Energy "quality" & irreversible processes (7.3) – this section is as short as it is well-written!

$E_{thermal}$ is of lesser quality because it can't be transformed 100% to other forms. As $E_{thermal}$ increases and other forms decrease, energy quality declines. → Revisit the simple pendulum.

Quiz # 51: When your book falls to the floor, is this a thermodynamically irreversible process? Is energy conserved?

(a) Yes Yes (b) No Yes (c) No No (d) Yes No

Quiz # 52: A heat engine provides 2000 J of work output, while exhausting 3000 J of $E_{thermal}$. Based on this information, can you calculate its efficiency?

(a) No, not enough info.
(b) 20%
(c) 40%
(d) 50%
(e) 2/3 (67%)