Conceptual Physics

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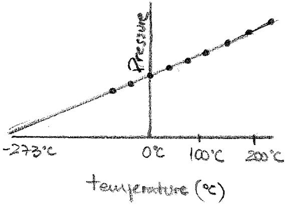
- Subjective sensation (familiar to everyone):
  when you touch something hot
  heat goes into your hand and burns it
- We talk of tansfer of heat
  e.g. ☞ from one object (the radiator) to another (your hand)
- Fact that radiator is hot
  expressed as "radiator is @ high *temperature*"
- Heat and work are mutually convertible:
  you can do work and get heat or use heat and do work
  (a car engine or steam engine)
- The catch is ☞ when you go from heat to useful work
  you never achieve 100% conversion
  there is always some heat wasted
- Reason for this will be given in today's class

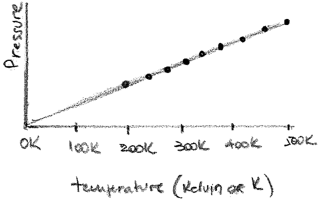
- Thermal energy ☞ random motion of molecules in matter sample which constitutes form of kinetic energy
- Temperature ☞ measure of average kinetic energy/molecule
- Temperature ☞ generally measured in Celsius or Farenheit
- Relation between Fahrenheit (F) and Celsius (C) scales

$$\mathrm{F} = \frac{9}{5}\mathrm{C} + 32$$

- It'll be convenient to talk about temperature in absolute scale
- Define absolute zero of temperature to correspond with point where all molecular motion ceases

- For given V of gas ☞ plot pressure as function of temperature





- Line extrapolated to $P = 0$ ☞ $T = -273^\circ$C for absolute zero
- Make absolute zero $T = 0^\circ$K ☞ freezing water is $T = 273^\circ$K
- Room temperature (68°F) is $20^\circ\text{C} = (273 + 20)^\circ\text{K} = 293^\circ\text{K}$
- We can never reach absolute zero (0°K)
  but temperatures as low as $5 \times 10^{-10\circ}$K have been reached

- Heat is *also* kinetic energy ☞ moving energy
- It is kinetic energyof zillions of atoms in material
  vibrating (in solid) or zapping around (in gas) in a random way
  going nowehere in particular
- *Heat is random energy of atoms and molecules*
- This is very different from organized energy
- It is like throwing bag of hot popcorn (organized energy)
  vs.
  letting them pop around inside popper (random energy)
- Popcorn popping very quickly has a lot of heat energy

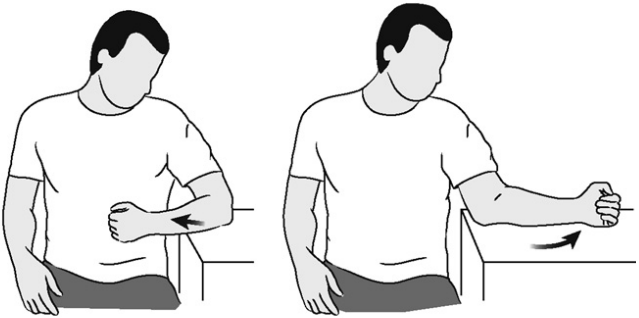
- Total heat energy of material depends on two things:
  1. how many atomos there are
  2. how energetic each atom is (on average)

- Heat energy Q can be expressed as product of number of atoms N and average randon energy of single atom $\langle \varepsilon \rangle$

$$Q = N \langle \varepsilon \rangle$$

- *Temperature* ☞ direct measurement of second factor: average energy of an atom
- High temperature means peppy atoms
- Low temperature means sluggish atoms
- When atoms are so sluggish that they don't move you've hit bottom in temperature scale ☞ *absoulte zero* which is $T = -273°$C ☞ very cold!

- When you push your hand across table
  (mechanical energy)
- you set molecules at surface of table
  into random vibration and create heat energy
  (friction in this case)



- You touch hot poker ☞ madly vibrrating atoms on surface of poker bombard molecules of your skin
- these start vibrating ☞ causing all kind of neurochemical reactions which tell your brain: “It’s hot, let go!”

- Important thing to know here
  same work W makes the same amout of heat Q *always*

- Equivalence will be given by example:
  for each 50 pounds of force which are pushed through one foot
  you make enough heat to raise T of 1 oz of water by about 1°F

- You can also push with force of 5 lb through 10 ft
  or with 10 lb through 5 ft
  as long as force $\times$ distance = 50 lb ft

- If you push twice as hard (100 lb) through one foot
  you make twice heat

- Rremember ☞ Q and W are interconvertible in definite proportions
  $1,000 \text{ ft lb} = 1.28 \text{ Btu} = 1/3 \text{ Cal}$ or $1 \text{ Btu} = 779 \text{ ft lb}$

- This is an expression of conservation of energy
- Energy can cross boundaries of closed system as heat or work
- By system ☞ we mean well-defined group of particles or objects
- Heat = Q ☞ energy transfer across system boundary
  due solely to T difference between system and environment
- For closed system ☞ first law of thermodynamics reads

$$E_{\rm in} - E_{\rm out} = \Delta E_{\rm system}$$

$E_{\rm in} = Q_{\rm in} + W_{\rm in}$ ☞ total energy entering system
$E_{\rm out} = Q_{\rm out} + W_{\rm out}$ ☞ total energy leaving system
$\Delta E_{\rm system} = E_{\rm final} - E_{\rm initial}$ ☞ change in total energy of system

- Each m^3 of air at room T has about 3×10^{25} molecules zipping around at random
- Average kinetic energy of each atom in air

$$\langle \varepsilon \rangle = \frac{3}{2}\, k_B\, T$$

Boltzmann constant ☞ $k_B = 1.380 \times 10^{-23}\ \mathrm{J}\ {}^\circ\mathrm{K}^{-1}$

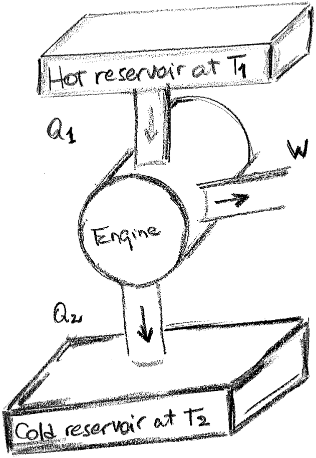
- Joule (J) ☞ work done by force of 1 N when its point of application moves 1 m in direction of action of force
- Total kinetic energy of all these molecules is about 347 Btu
- Room may be thought of as *reservoir* of thermal energy @ $T = 70^\circ$F (or 295°K)

- Question ☞ Is it possible to extract *some* of this thermal energy and change it *entirely* into useful work? (such as turning a generator)
- There is no contradiction here with conservation of energy but it is a fact that no such process is known
- This negative statement ☞ result of everyday experience
- *second law of thermodynamics*:

  It is impossible to construct an engine that, operating in a cycle, will produce no effect other than extraction of heat from a reservoir and performance of an equivalent amount of work
- Reduced to its simplest terms
  important characteristics of heat-engine cycles are...

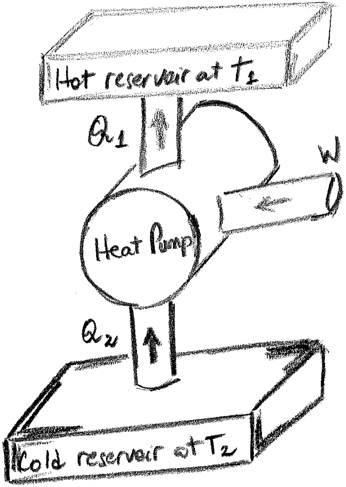
Heat engine

- Q_1 ☞ heat taken from boiler
- W ☞ work done
- Q_2 ☞ heat transferred to condenser
- $Q_1 = W + Q_2$



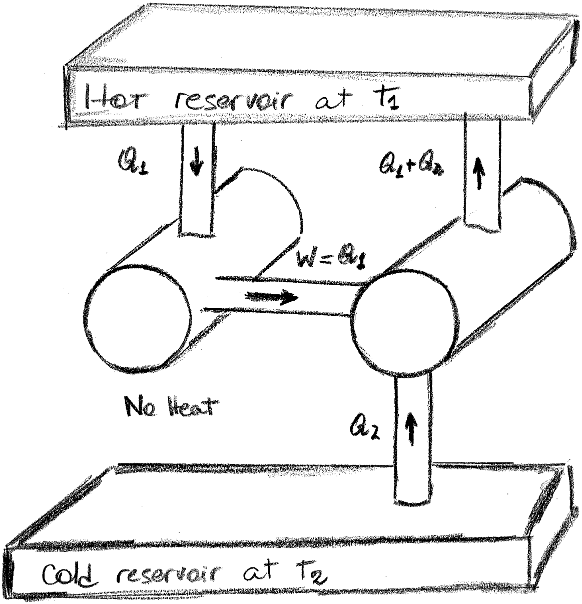
Refrigerator (or air conditioner)

- Q_2 ☞ heat taken from refrigerator (by coolant)
- W ☞ energy pumped in by motor
- Q_1 ☞ heat given up to surrounding air
- $Q_1 = W + Q_2$



- Using idea of refrigerator ☞ we can show that:
  violation of 2nd law would make it impossible to construct device which (operating in a cycle) will produce *no effect* other than transfer of heat from a cooler body to a warmer body
- Since this never happens ☞ for statistical reasons
  we can then see why *second law* works
- *Proof* is as follows:
  - Suppose we had an engine which violates the second law
    (rejects no heat to the cold reservoir)
  - Then ☞ we could use work liberated by engine to run refrigerator
    which operates between same two reservoirs
    and takes heat Q_2 from cold and puts $W + Q_2 = Q_1 + Q_2$ into hot
  - Net result is transfer of heat from cold to hot reservoir
    with nothing else occurring
  - This is impossible ☞ so engine is impossible

Engine which violates the 2nd law of thermodynamics



- Efficiency

$$\frac{\text{work out}}{\text{heat extracted from hot reservoir}} = \frac{W}{Q_1}$$

- *Maximum* efficiency

$$\text{maximum efficiency} = \eta_{\max} = \frac{T_1 - T_2}{T_1}$$

T_1 and T_2 are in $^\circ$K.

- E.g. ☞ steam engine
  - boiler heating the steam to 400°C $(= 670^\circ$K)
  - condenser operating at 100°C $(= 370^\circ$K)
  - Maximum theoretical efficiency

$$\eta_{\max} = \frac{670 - 370}{670} \simeq 45\%$$

- Coefficient of performance of refrigerator

$$\text{CoP} = \frac{\text{heat removed from cold reservoir}}{\text{work done (electrical energy used)}} = \frac{Q_2}{W} = \frac{Q_2}{Q_1 - Q_2}$$

- Maximum value

$$\text{CoP}_{\text{max}} = \frac{T_2}{T_1 - T_2}$$

- E.g. ☞ air conditioner operating between:
  - room at $70°$F $(= 295°$K)
  - outdoors at $85°$F $(= 395°$K)
  - Maximum theoretical coefficient of performance

$$\text{CoP}_{\text{max}} = \frac{295}{309 - 295} = \frac{295}{14} = 20$$