I. THE FIRST LAW OF THERMODYNAMICS

A. THE FIRST LAW IS A STATEMENT ABOUT CONSERVATION OF ENERGY, BROKEN-DOWN INTO INTERNAL ENERGY OF A SYSTEM, HEAT EXCHANGED TO/FROM IT, AND WORK DONE ON/BY IT.

FIRST LAW: "ENERGY CAN NEITHER BE CREATED NOR DESTROYED. IT CAN ONLY BE TRANSFERRED FROM ONE SYSTEM TO ANOTHER, OR FROM ONE FORM TO ANOTHER."

B. KNOWN FORMS OF ENERGY

- KINETIC ENERGY (ENERGY OF MOTION)
  - TRANSLATIONAL
  - VIBRATIONAL
  - ROTATIONAL
- INTERACTION ENERGY (FROM INTERACTION FORCES)
  - STRONG FORCE
    - BINDS NUCLEI TOGETHER. ABOUT 10^2 TIMES STRONGER THAN EM FORCE.

- ELECTROMAGNETIC FORCE
  - ELECTRO - FROM COULOMB FORCE MAGNETIC FROM MAGNETIC FORCE, (WE WILL STUDY THESE LATER.)
  - ALL PARTICLES WITH <u>CHARGE</u> EXPERIENCE EM FORCE.
- WEAK FORCE
  - RELATED TO SPECIAL TYPES OF PARTICLE-DECAY / INTERACTION PROCESSES
  - ULTIMATELY UNDERSTOOD AS JUST PART OF ONE THEORY INCLUDING ELECTROMAGNETISM (ELECTROWEAK THEORY.)
  - E.g., "Beta-Decay"

$$\underset{\text{neutron}}{n^0} \xrightarrow{\text{decay}} \underset{\text{proton}}{p^+} + \underset{\text{electron}}{e^-} + \underset{\text{electron antineutrino}}{\bar{\nu}_e}$$

(More about this in 1C).

- GRAVITATIONAL FORCE
  - THIS IS THE WEAKEST FORCE OF ALL, BUT IT IS WHAT KEEPS US STUCK TO THE EARTH, PREVENTING US FROM SUDDENLY FLYING OFF INTO SPACE.
  - INTERESTINGLY, ITS THE FORCE THAT WE'VE HISTORICALLY HAD THE MOST TIME TO STUDY, BUT WE KNOW THE LEAST ABOUT IT.

- THE STRONG, ELECTROMAGNETIC AND WEAK FORCES ARE VERY WELL-UNDERSTOOD BY ONE THEORY CALLED THE STANDARD MODEL. GRAVITY REMAINS A MYSTERY. STRING THEORY MAY PROVIDE AN ANSWER.

- MASS-ENERGY

  IN 1C, YOU'LL FIND-OUT THAT MASS ITSELF IS JUST ANOTHER FORM OF ENERGY. A TINY BIT OF MASS CAN BE CONVERTED INTO A HUGE AMOUNT OF ENERGY (THIS IS THE BASIS OF NUCLEAR REACTORS AND ATOMIC BOMBS.)

- THE TOTAL ENERGY OF ANY SYSTEM IS JUST THE SUM OF ALL ITS DIFFERENT KINETIC, INTERACTION, AND MASS-ENERGIES.

  ALL OF THE ABOVE ENERGIES CAN BE PRESENT IN SOME SYSTEM AT THE SAME TIME, BUT THE EFFECTS OF ANY ONE OR MORE OF THEM MAY (AND USUALLY ARE) NEGLIGIBLE BY COMPARISON TO OTHERS UNDER STUDY.

Eg, THE ROTATIONAL KINETIC ENERGY OF A MONATOMIC GAS SUCH AS He IS USUALLY NEGLIGIBLE, BUT IT CAN NOT BE GENERALLY NEGLECTED FOR DIATOMIC OR POLYATOMIC MOLECULES SUCH AS N_2 OR CO_2.

C. MATHEMATICAL STATEMENT OF FIRST LAW

$$dU = đQ - đW$$

(The đ is a technical distinction that we won't demand be made in this course.)

$$\boxed{dU = dQ - dW}$$

FIRST LAW OF THERMODYNAMICS

(Change in Internal Energy of System) =
(heat added to (taken from) system)
− (Work done by (on) system on (by) external environment)

- THE FIRST LAW CAN TRULY BE CONSIDERED TO BE A LAW, IN THE PUREST SENSE OF THE WORD. NO VIOLATION, UNDER ANY CONDITIONS, HAS EVER BEEN OBSERVED.
- THIS IS DIFFERENT THAN MANY OTHER "LAWS", SUCH AS THE IDEAL GAS LAW, WHICH, e.g., WILL BREAK-DOWN IF GAS DENSITIES BECOME TOO LARGE, ETC.

II. MICROSCOPIC VS. MACROSCOPIC SYSTEMS AND QUANTITIES.

CONSIDER WHAT WE WERE DOING WHEN WE CAME UP WITH OUR FIRST REAL QUANTITATIVE DEFINITION OF WHAT TEMPERATURE IS:

WE IMAGINED THAT A GAS WAS COMPRISED OF SOME LITTLE PARTICLES OF MATTER THAT WEREN'T REALLY INTERACTING MUCH, THEIR TOTAL ENERGY WAS GIVEN BY THEIR AVERAGE KINETIC ENERGIES, AND WE APPLIED NEWTONIAN MECHANICS (Physics 1A) TO DETERMINE THE FORCES THAT ALL OF THESE LITTLE PARTICLES WOULD EXERT ON THE WALLS OF SOME VESSEL THAT CONTAINED THEM.

WHAT WE FOUND IN THE END WAS THAT THIS THINKING LEAD US OUT OF THE DARKNESS OF "SPOOKY CALORIC" AND GAVE US FOR THE FIRST TIME AN ACTUAL QUANTITATIVE DEFINITION FOR JUST WHAT WE MEAN BY TEMPERATURE:

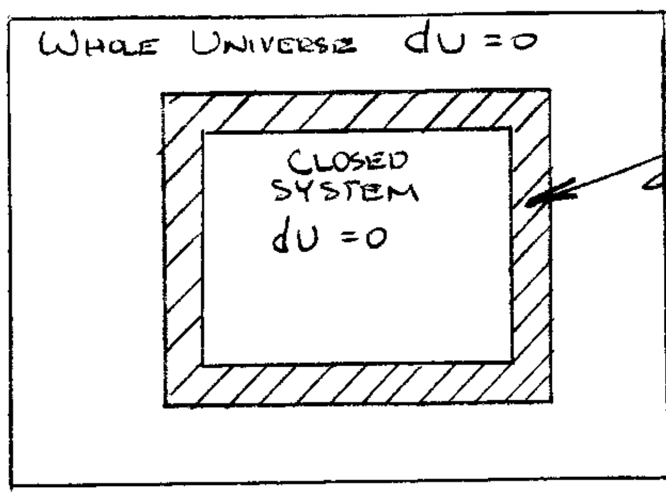
$$T = \frac{2}{3} \frac{\langle K.E. \rangle}{K_B}$$

NOTICE THAT WE COULD ONLY COME UP WITH THIS BY LOOKING AT A LARGE NUMBER OF PARTICLES. WE CAN'T VIEW TEMPERATURE AS SOMETHING INTRINSIC TO A SINGLE PARTICLE. IT ONLY MAKES SENSE WHEN WE TALK ABOUT LARGE COLLECTIVES OF THINGS ALL AT ONCE.

TEMPERATURE, PRESSURE AND ENTROPY ARE MACROSCOPIC QUANTITIES. THEY HAVE NO MEANING FOR INDIVIDUAL PARTICLES.

III. CLOSED SYSTEMS

- AN ESSENTIAL CONCEPT IN THERMODYNAMICS IS THAT OF A CLOSED SYSTEM.



"THERMODYNAMIC INSULATOR"

NO ENERGY CAN BE EXCHANGED WITH REST OF UNIVERSE. ISOLATE SYSTEM OR SYSTEMS TO STUDY THEIR BEHAVIOR ALONE.

IV. THERMAL PROCESSES

A. THERE ARE FOUR BASIC THERMODYNAMIC PROCESSES:

- $dT = 0$ (isothermal). The temperature of the system under study is not changing
- $dP = 0$ (isobaric). The volume of the system under study is not changing
- $dQ = 0$ (adiabatic). No heat is leaving or entering system under study.
- $dV = 0$ (isochoric). The volume of the system under study is not changing

B. TO DO ANY ACTUAL THERMODYNAMIC CALCULATIONS, ONE MUST KNOW:

(1) How to express the particular system's internal energy.

- E.g., for a monatomic ideal gas, we found that

$$U = \frac{3}{2} nRT$$

(2) THE SYSTEMS EQUATION OF STATE

(this tells one how P, V, N, T are related for a particular system)

- E.g., for a monatomic ideal gas we found this is

$$PV = nRT$$

(actually also applies to diatomic and polyatomic gases, as well as many other surprises.)

NEXT LECTURE, WE WILL STUDY THESE FOUR BASIC PROCESSES FOR AN IDEAL GAS.

IV. A NOTE ABOUT THE SIGNS OF dU, dQ, dW (or, $\Delta U, \Delta Q, \Delta W$)

YOUR TEXT EXPRESSES THE FIRST LAW WITH A MINUS SIGN:

$$dU = dQ - dW$$

THE CHOICE OF SIGN IS MERELY A MATTER OF CONVENTION, AND YOU SHOULD TRANSLATE IT AS FOLLOWS:

$dU > 0 \Rightarrow$ INTERNAL ENERGY OF SYSTEM IS INCREASING ("ENERGY IN")

$dU < 0 \Rightarrow$ INTERNAL ENERGY OF SYSTEM IS DECREASING ("ENERGY OUT")

$dQ > 0 \Rightarrow$ Heat entering system ("ENERGY IN")

$dQ < 0 \Rightarrow$ Heat LEAVING SYSTEM ("ENERGY OUT")

— BUT THEN SOMETHING FUNNY HAPPENS —

$dW > 0 \Rightarrow$ SYSTEM IS DOING WORK <u>ON</u> EXTERNAL ENVIRONMENT ("ENERGY-OUT" → BACKWARDS RELATIVE TO ABOVE!)

$dW < 0 \Rightarrow$ SYSTEM IS HAVING WORK DONE ON IT ("ENERGY-IN")

THIS IS THE SIGN CONVENTION BEING USED IN YOUR TEXT. BUT, IF YOU PREFER, YOU CAN USE A DIFFERENT CONVENTION THAT MAKES MORE SENSE:

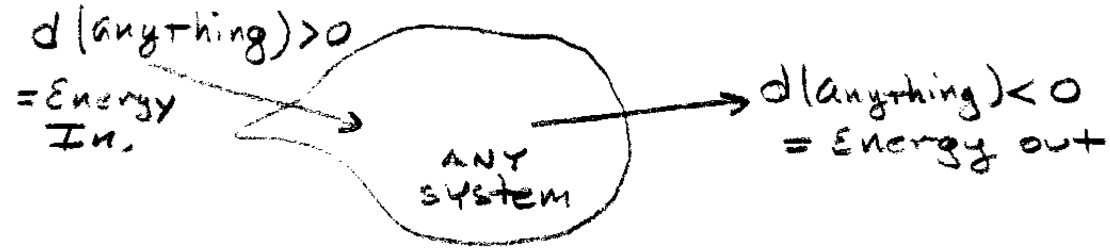
$$dU = dQ + dW$$

WITH THIS CHOICE, YOU CAN SAY THAT IF <u>ANY</u> OF THE QUANTITIES dU, dQ, dW ARE GREATER THAN ZERO (POSITIVE) That represents ENERGY ENTERING THE SYSTEM

$dU > 0 \Rightarrow$ ENERGY-IN. $\quad dU < 0$ OUT

$dQ > 0 \Rightarrow$ ENERGY-IN. $\quad dQ < 0$ OUT

$dW > 0 \Rightarrow$ ENERGY-IN. $\quad dW < 0$ OUT.



The convention $dU = dQ + dW$, makes it very easy to keep track of energy being supplied-to or taken-from the system.

If you use it, just notice that your sign for work (dW) will just be the negative of the sign for work used by someone who likes to say

$$dU = dQ - dW.$$