ENERGY CALCULATIONS

HOW MUCH ENERGY DOES IT TAKE TO WALK UP THE STEPS FROM COLLEGE WALK TO LOW LIBRARY ASSUMING THE ONLY ENERGY NEEDED IS THAT TO INCREASE THE GRAVITATIONAL POTENTIAL ENERGY OF YOUR BODY, $\Delta V = m \times g \times \Delta h$? NOTE: $g = 9.8 \text{ m s}^{-2}$.

HOW MANY TIMES DO YOU HAVE TO MAKE THIS CLIMB TO "WORK OFF" ONE SNICKERS BAR?

ANSWERS TOMORROW.
ENERGY

ENERGY NEEDED = $\Delta V$

$\Delta V = m \times g \times \Delta h = 71 \text{ kg} \times 9.8 \text{ m s}^{-2} \times \Delta h$

$\Delta h = 56 \text{ steps} \times 4.875 \text{ inch step}^{-1} = 273 \text{ inches}$

$\Delta h = 6.93 \text{ m}$

$E = \Delta V = 4.8 \times 10^3 \text{ J} = 1.1 \text{ kcal} = 1.1 \text{ Calories}$

ONE SNICKERS BAR SUPPLIES 280 CALORIES, SO IT TAKES ABOUT 250 SUCH CLIMBS TO EXPEND THE ENERGY EQUAL TO THAT IN ONE SNICKERS BAR.
HEAT CAPACITY CALCULATIONS

HOW MANY SNICKERS BARS PROVIDE ENOUGH ENERGY TO HEAT THE WATER IN A COMMON HOUSEHOLD WATER HEATER (40 GALLONS) FROM 55 FAHRENHEIT TO 130 FAHRENHEIT?

TAKE A GUESS AS TO HOW MANY CUBIC FEET (AT STP) OF NATURAL GAS (MOSTLY METHANE) WOULD HAVE TO BE BURNED TO DO THE SAME THING?

ANSWERS TOMORROW.
HEAT CAPACITY CALCULATIONS

THE ANSWER

\[ q = m \times c_s \times \Delta T \]
\[ m = 40 \text{ gal} \times 3.785 \text{ L gal}^{-1} \times (1.0 \times 10^3 \text{ g L}^{-1}) \]
\[ \Delta T = 75^\circ \text{F} = 42^\circ \text{K} \]
\[ q = (1.5 \times 10^5 \text{ g}) \times (1 \text{ cal g}^{-1} \text{ K}^{-1}) \times (42 \text{ K}) \]
\[ q = 6.3 \times 10^6 \text{ cal} = 6.3 \times 10^3 \text{ Calories} = 23 \text{ SNICKERS} \]

ONE CUBIC FOOT OF METHANE AT STP HAS AN ENERGY CONTENT OF ABOUT 4.5 \times 10^3 \text{ kcal}, SO WE NEED ABOUT 1.4 CUBIC FEET.
HEAT CAPACITY CALCULATIONS

THERE ARE ABOUT 100 MILLION SUCH WATER HEATERS IN THE US. IF ALL THE ENERGY IN ALL THOSE WATER HEATERS WERE TRANSFERRED AS HEAT TO THE EARTH ESTIMATE HOW MUCH THE TEMPERATURE RISE OF THE EARTH WOULD BE. NOTE: TABLE 10-1 PROVIDES ALL THE INFORMATION YOU NEED EXCEPT FOR THE MASS OF THE EARTH, WHICH IS 6 X 10^{24} kg.

ANSWER TOMORROW.
THE RELATION OF HEAT TO WORK

THE MECHANICAL EQUIVALENT OF HEAT IS ESTABLISHED BY MEASURING THE TEMPERATURE INCREASE IN AN OBJECT WHEN A PRECISE AMOUNT OF WORK IS DONE ON IT.

James Joule

Joule's Experiment
THE RELATION OF HEAT TO WORK

JOULE'S EXPERIMENT ESTABLISHED THAT WORK CAN BE QUANTITATIVELY CONVERTED INTO HEAT

1. WORK DONE BY THE WEIGHTS ON THE WATER:
   \[ w_{\text{water}} = - m_{\text{weight}} \times g \times \Delta h. \]

2. THE ONLY EFFECT OF THIS WORK WAS TO RAISE THE TEMPERATURE OF THE WATER.

3. SO, HEAT WAS ABSORBED BY THE WATER:
   \[ q = m_{\text{water}} \times c_{s,\text{water}} \times \Delta T. \]

CONCLUSION

\[ - m_{\text{weight}} \times g \times \Delta h = m_{\text{water}} \times c_{s,\text{water}} \times \Delta T \]
\[ w = q \]
THE FIRST LAW OF THERMODYNAMICS

- THE FIRST LAW OF THERMODYNAMICS states that energy is conserved if you take account of both heat and work:

\[ \Delta E = q + w \]

- Note however that this describes the change in energy, not the energy itself.

- Work and heat are transfers of energy from one body to another, so two objects are involved.
THE FIRST LAW OF THERMODYNAMICS

THE SIGN OF $q$

WE PREVIOUSLY DEFINED HEAT FROM AN EXPERIMENT INVOLVING THE TEMPERATURE CHANGE OF TWO BODIES IN CONTACT:

$$q = m_1 \times c_{s,1} \times \Delta T_1$$

and

$$q = m_2 \times c_{s,2} \times \Delta T_2$$

THESE TWO $q$ DIFFER IN SIGN. WHICH ONE GOES INTO THE FIRST LAW EQUATION?

IT DEPENDS ON WHICH ONE YOU ARE INTERESTED IN.
THE FIRST LAW OF THERMODYNAMICS

THE SYSTEM AND THE SURROUNDINGS

HEAT IS A TRANSFER OF ENERGY FROM ONE BODY TO ANOTHER. FOR ONE $q$ IS POSITIVE, AND FOR THE OTHER $q$ IS NEGATIVE. ONE BODY GAINS ENERGY ($E$ INCREASES) WHILE THE OTHER LOSES ENERGY ($E$ DECREASES). $\Delta E_1 = - \Delta E_2$.

WE CALL THE BODY WE ARE INTERESTED IN THE SYSTEM.
WE CALL THE OTHER BODY THE SURROUNDINGS.

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THE SYSTEM AND SURROUNDINGS

THE SIGN CONVENTION ON $q$ and $w$

- $q$ IS **POSITIVE** IF HEAT FLOWS **TO** THE SYSTEM.
- $q$ IS **NEGATIVE** IF HEAT FLOWS **FROM** THE SYSTEM.
- $w$ IS **POSITIVE** IF WORK IS DONE **ON** THE SYSTEM.
- $w$ IS **NEGATIVE** IF WORK IS DONE **BY** THE SYSTEM.

\[ \Delta E_{\text{SURROUNDINGS}} = - \Delta E_{\text{SYSTEM}} \]
\[ q_{\text{SURROUNDINGS}} = - q_{\text{SYSTEM}} \]
\[ w_{\text{SURROUNDINGS}} = - w_{\text{SYSTEM}} \]
THE FIRST LAW OF THERMODYNAMICS

THE SIGN CONVENTION ON \( q \) AND \( w \) MAKES SENSE

THE SYSTEM AND THE SURROUNDINGS ARE IN CONTACT WITH EACH OTHER, BUT ISOLATED FROM EVERYTHING ELSE, SO THE COMBINATION HAS A FIXED (CONSTANT) VALUE OF \( E \).

\[
\Delta E_{\text{SURROUNDINGS}} + \Delta E_{\text{SYSTEM}} = 0 \\
q_{\text{SURROUNDINGS}} + q_{\text{SYSTEM}} = 0 \\
w_{\text{SURROUNDINGS}} + w_{\text{SYSTEM}} = 0
\]
THE FIRST LAW OF THERMODYNAMICS

KINDS OF WORK AND THE SIGN OF THE WORK

PV WORK: \( w = - P \Delta V \)
NEGATIVE SIGN BECAUSE WORK IS DONE ON THE SYSTEM IF \( \Delta V \) IS NEGATIVE

WORK AGAINST GRAVITY: \( w = m g \Delta h \)
POSITIVE SIGN BECAUSE WORK IS DONE ON THE SYSTEM IF \( \Delta h \) IS POSITIVE
THE IMPORTANCE OF PV WORK

FOSSIL FUEL AND NUCLEAR ELECTRIC POWER GENERATION OPERATE BY PV WORK

![Diagram of a nuclear power plant with labels:
A: Containment Structure
B: Control Rods
C: Reactor
D: Steam Generator
E: Steam Line
F: Pump
G: Generator
H: Turbine
I: Cooling Water Condenser
J: Cooling Tower]
THE IMPORTANCE OF PV WORK

OTHER POWER GENERATION OPERATES BY PV WORK

GEOTHERMAL POWER GENERATION

Geothermal steam extraction system for electricity production.
THE IMPORTANCE OF PV WORK

PV WORK MAKES YOU COMFORTABLE

AUTO SHOCK ABSORBERS
THE IMPORTANCE OF PV WORK

PV WORK MAY SAVE YOUR LIFE

AUTO AIRBAGS
THE IMPORTANCE OF PV WORK

YOU DO PV WORK EVERY MOMENT OF YOUR LIFE

HUMAN RESPIRATION
PV WORK

A PISTON MOVING IN A CYLINDER
PV WORK

WORK DEPENDS ON PATH

\[ w = - P \times \Delta V \] (FOR P CONSTANT)

\[ P_{\text{ext}} = 29 \text{ kPa} \]

\[ P_{\text{ext}} = 9 \text{ kPa} \]

\[ W_{a-d-c} > W_{a-c} > W_{a-b-c} \]
CALCULATION OF PV WORK

\[
W_{a-d-c} = W_{a-d} = -P_{ad} \times (V_d - V_a) = -29 \text{ kPa} \times (4 - 1) \text{ m}^3 = -87 \text{ kJ}
\]

\[
W_{a-b-c} = W_{b-c} = -P_{bc} \times (V_c - V_b) = -9 \text{ kPa} \times (4 - 1) \text{ m}^3 = -27 \text{ kJ}
\]

\[
P_{ext} = 9 \text{ kPa}
\]

\[
P_{ext} = 29 \text{ kPa}
\]
PV DIAGRAMS

P CONSTANT & n CONSTANT & V INCREASES $\rightarrow$ T INCREASES

Pressure (kPa)

PV = nRT
PV/nR = T

P DECREASES & n CONSTANT & V CONSTANT $\rightarrow$ T DECREASES

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CALCULATION OF PV WORK

RELATING $q$, $w$, $P$, $V$, AND $T$

IN THE EXAMPLE WE JUST CONSIDERED
CALCULATE THE HEAT $q$ FOR EACH STEP
FOR A SYSTEM IN WHICH OXYGEN IS THE GAS,
BEHAVING IDEALLY.

ANSWER TOMORROW.
YOUR 7-YEAR-OLD NEPHEW IS HAVING A BIRTHDAY PARTY. YOU ARE ASKED TO BLOW UP 75 BALLOONS. EACH BALLOON IS NO BIGGER THAN YOUR THUMB WHEN YOU START, BUT IS A SPHERE OF DIAMETER 25 CM WHEN INFLATED. HOW MUCH WORK WILL YOU PERFORM IN DOING THIS IF YOU ASSUME THAT THE BALLOON IS PERFECTLY ELASTIC?

ANSWER TOMORROW.
STATE FUNCTIONS

STATE FUNCTIONS DEPEND ONLY ON P, V, AND n

A **STATE FUNCTION** IS A THERMODYNAMIC QUANTITY THAT DEPENDS ONLY ON "WHERE YOU ARE" NOT "HOW YOU GOT THERE."

IN THERMODYNAMICS "WHERE YOU ARE" MEANS A PARTICULAR SET OF VALUES FOR THOSE QUANTITIES THAT DEFINE THE **EQUATION OF STATE**.
STATE FUNCTIONS

THE EQUATION OF STATE


IDEAL GAS EQUATION OF STATE
PV = nRT OR PV/nR = T OR nRT/V = P

VAN DER WAALS EQUATION OF STATE

\[\frac{(P + a(n^2/V^2))(V-nb)}{nR} = T\]

P, V, AND T OR ANY OTHER THREE OF THESE VARIABLES SPECIFY THE STATE OF THE SYSTEM.
STATE FUNCTIONS

SPECIFYING P, V, AND n DETERMINES THE VALUE OF ANY STATE FUNCTION

E IS ONE STATE FUNCTION …WITH MORE TO COME

WE WILL USE UPPER CASE LETTERS FOR STATE FUNCTIONS.

WHAT IS NOT A STATE FUNCTION? q and w
THERMODYNAMICS

THERMO (HEAT) AND DYNAMICS (WORK)
THERMO (HEAT) AND DYNAMICS (WORK)

q ↔ w

WHERE DOES q "COME FROM?"

FROM CHEMICAL REACTIONS, ESPECIALLY COMBUSTION AND METABOLISM

CHEMICAL REACTIONS ALSO CAN LEAD DIRECTLY TO w WITHOUT "GOING THROUGH" q.

WHICH BRINGS US TO CHEMICAL THERMODYNAMICS
CHEMICAL THERMODYNAMICS

THERMOCHEMISTRY IS CHEMICAL THERMODYNAMICS
- MOST OF THE ENERGY USED IN THE WORLD COMES FROM THE BURNING OF FOSSIL FUELS.

- BURNING CONVERTS THE POTENTIAL ENERGY IN THE FUEL INTO MOLECULAR KINETIC ENERGY, WHICH IS TRANSFERRED AS HEAT TO SOME DEVICE THAT USES THIS HEAT TO DRIVE AN ENGINE THAT DOES WORK.
THE ENERGY HUMANS USE TO SURVIVE COMES FROM FOOD, WHICH IS JUST ANOTHER FUEL.

METABOLISM CONVERTS THE POTENTIAL ENERGY IN FOOD INTO THERMAL ENERGY TO KEEP YOU WARM AND PROVIDES FOR THE WORK THAT YOU DO.
THERMOCHEMISTRY IS THE QUANTITATIVE MEASUREMENT, ANALYSIS, AND PREDICTION OF THE ENERGY CONTENT OF CHEMICALS AND THE ENERGY CHANGE IN THEIR INTERCONVERSION.

- HOW DO WE DO THAT?

- WE ACTUALLY MEASURE THE HEAT TRANSFERRED IN A CHEMICAL REACTION USING A CALORIMETER.
CHEMICAL THERMODYNAMICS

THE CALORIMETER

- Measure the temperature rise in a sample of water upon some chemical reaction, often combustion.

- Use the heat capacity of water to convert this temperature rise to a heat transfer from/to the chemical sample to/from the water.
THE CALORIMETER