ENERGY

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: $g = 9.8\ m\ s^{-2}$.

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

ANSWERS TOMORROW.

ENERGY

THE ANSWER

JJV MASS

ENERGY NEEDED = ΔV

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

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

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

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

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

$q = m \times c_s \times \Delta T$

$m = 40 \text{ gal} \times 3.785 \text{ L gal}^{-1} \times (1.0 \times 10^3 \text{ g L}^{-1})$

$\Delta T = 75\text{F} = 42\text{K}$

$q = (1.5 \times 10^5 \text{ g}) \times (1 \text{ cal g}^{-1} \text{ K}^{-1}) \times (42 \text{ K})$

$q = 6.3 \times 10^6$ cal $= 6.3 \times 10^3$ Calories = 23 SNICKERS

ONE CUBIC FOOT OF METHANE AT STP HAS AN ENERGY CONTENT OF ABOUT 4.5×10^3 kcal, SO WE NEED ABOUT 1.4 CUBIC FEET.

HEAT CAPACITY CALCULATIONS

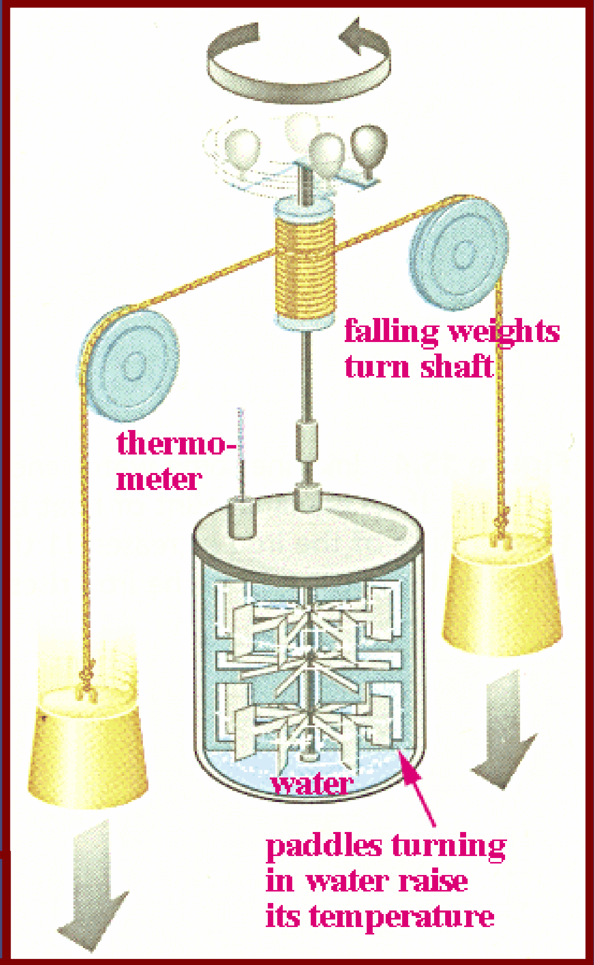
THERE ARE ABOUT 1OO MILLION SUCH WATER HEATERS IN THE US. IF ALL THE ENERGY IN ALL THOSE WATER HEATERS WERE TRANSFERRED AS HEAT TO THE EARTH ESTIMATE HOW MUCH THE TEMPERATURE RISE OF THE EARTH WOULD BE. NOTE: TABLE 10-1 PROVIDES ALL THE INFORMATION YOU NEED EXCEPT FOR THE MASS OF THE EARTH, WHICH IS 6×10^{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: $w_{water} = - m_{weight} \times g \times \Delta h$.
2. THE ONLY EFFECT OF THIS WORK WAS TO RAISE THE TEMPERATURE OF THE WATER.
3. SO, HEAT WAS ABSORBED BY THE WATER: $q = m_{water} \times c_{s,water} \times \Delta T$.

CONCLUSION

$$- m_{weight} \times g \times \Delta h = m_{water} \times c_{s,water} \times \Delta T$$

$$w = q$$

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 TEMPERTURE 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 POSTIVE, 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**

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.

$$\Delta E_{SURROUNDINGS} = -\Delta E_{SYSTEM}$$
$$q_{SURROUNDINGS} = -q_{SYSTEM}$$
$$w_{SURROUNDINGS} = -w_{SYSTEM}$$

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: $w = -P \times \Delta V$

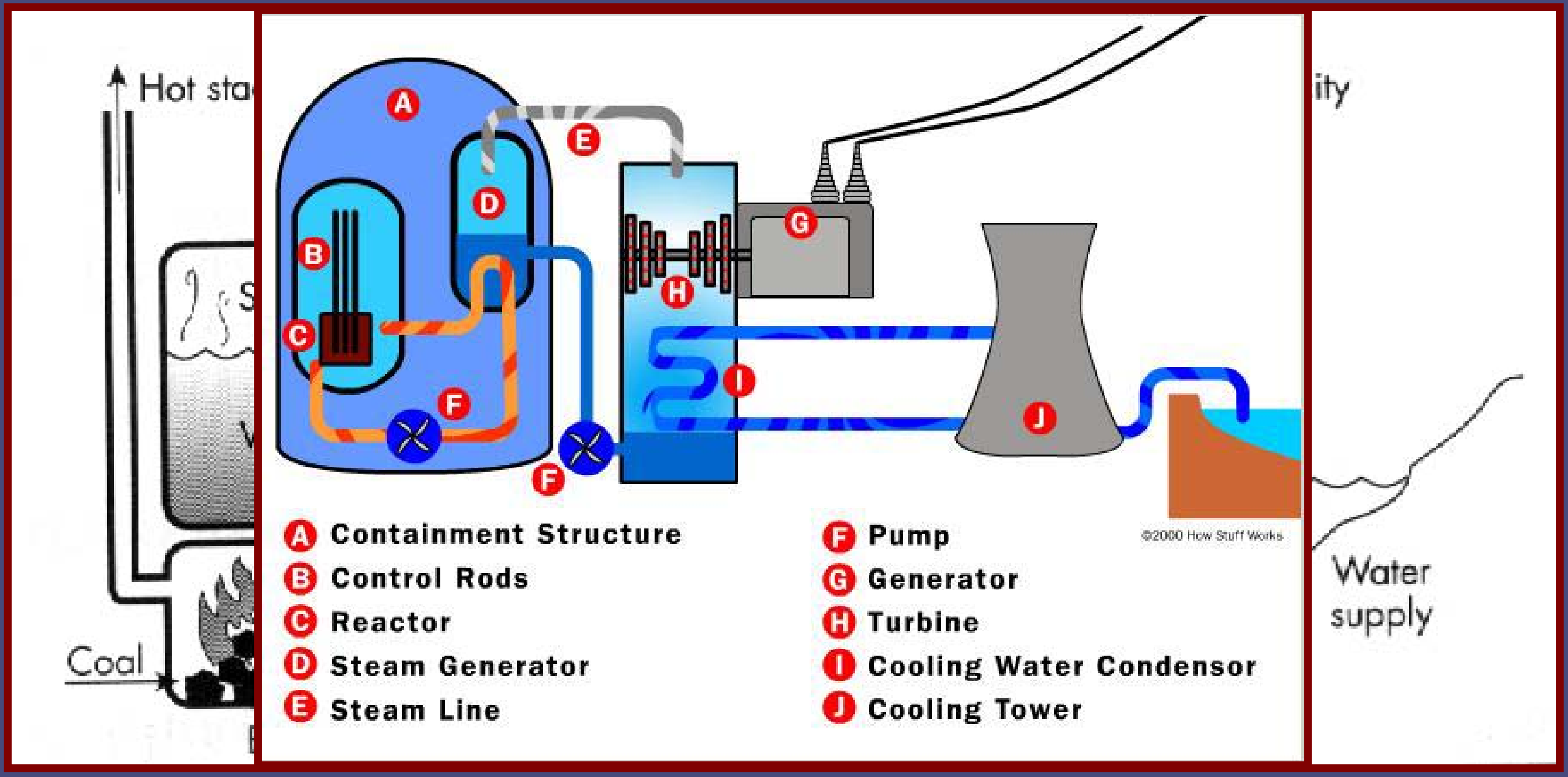
NEGATIVE SIGN BECAUSE WORK IS DONE ON THE SYSTEM IF ΔV IS NEGATIVE

WORK AGAINST GRAVITY: $w = m \times g \times \Delta h$

POSITIVE SIGN BECAUSE WORK IS DONE ON THE SYSTEM IF Δh IS POSITIVE

THE IMPORTANCE OF PV WORK

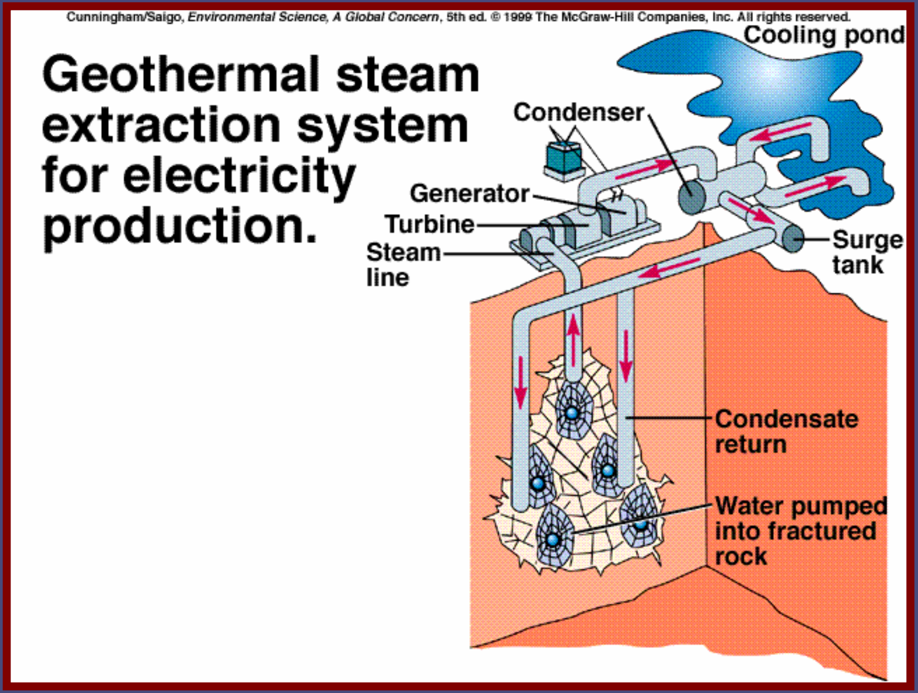
FOSSIL FUEL AND NUCLEAR ELECTRIC POWER GENERATION OPERATE BY PV WORK



THE IMPORTANCE OF PV WORK

OTHER POWER GENERATION OPERATES BY PV WORK

GEOTHERMAL POWER GENERATION



THE IMPORTANCE OF PV WORK

PV WORK MAKES YOU COMFORTABLE

AUTO SHOCK ABSORBERS

THE IMPORTANCE OF PV WORK

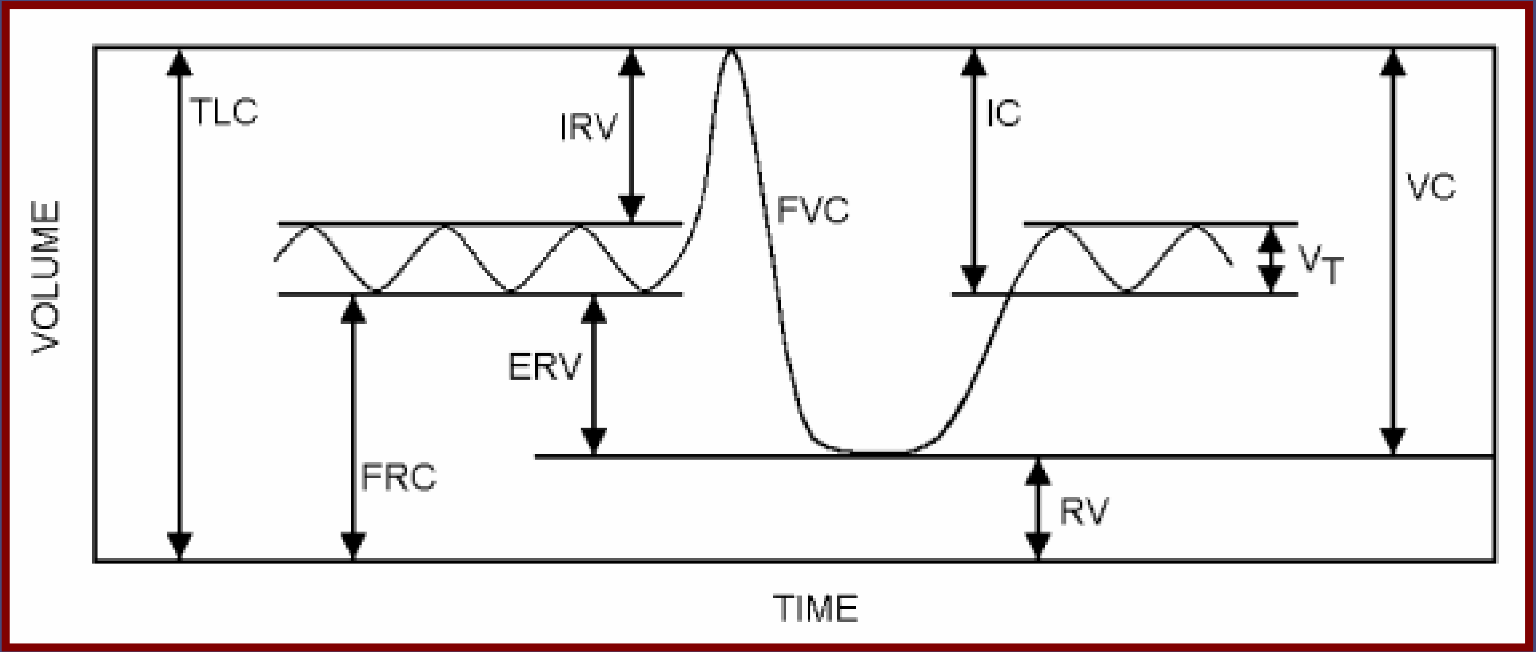
PV WORK MAY SAVE YOUR LIFE

AUTO AIRBAGS

THE IMPORTANCE OF PV WORK

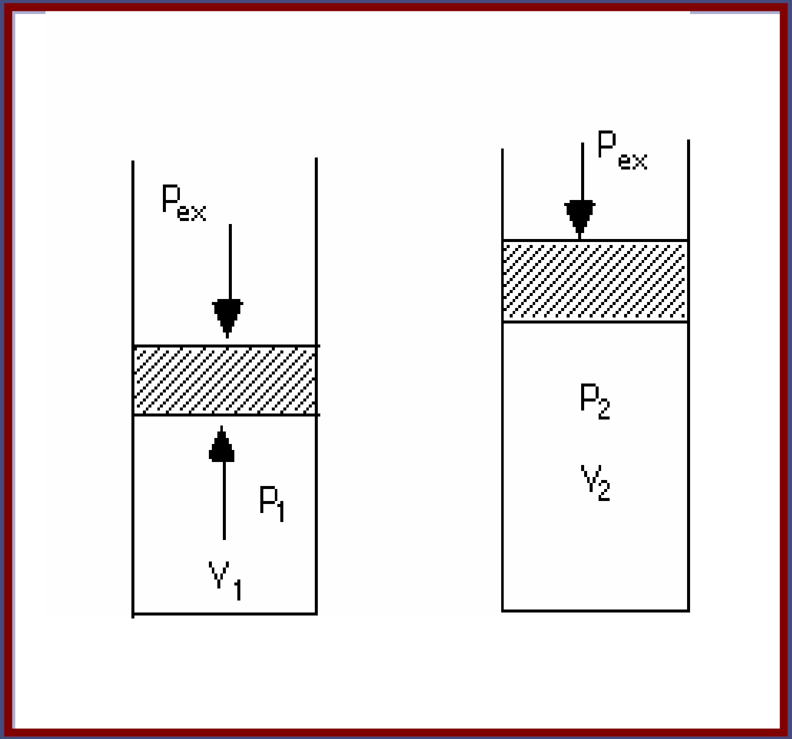
YOU DO PV WORK EVERY MOMENT OF YOUR LIFE

HUMAN RESPIRATION



PV WORK

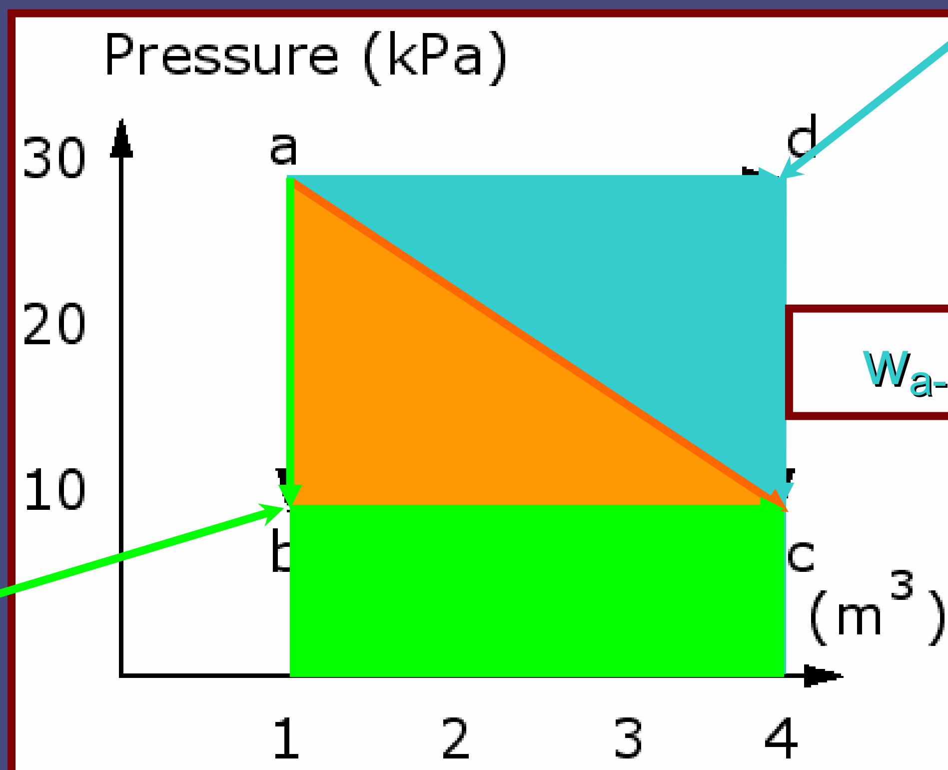
A PISTON MOVING IN A CYLINDER



PV WORK

WORK DEPENDS ON PATH

P_{ext} = 29 kPa

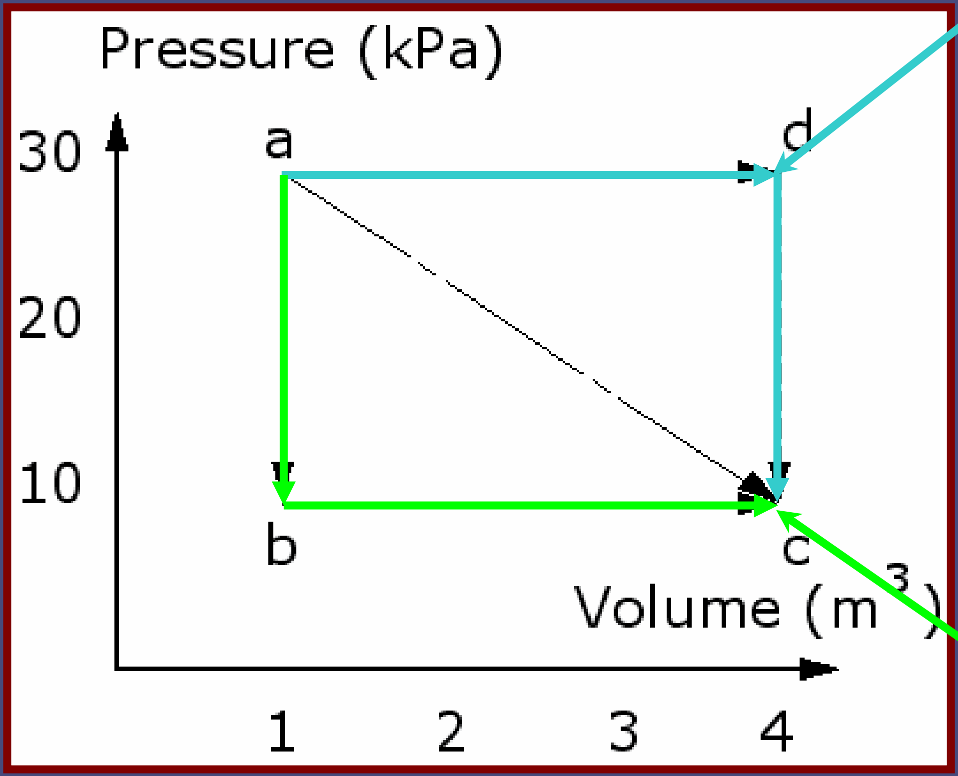


$w = - P \times \Delta V$
(FOR P CONSTANT)

$w_{a\text{-}d\text{-}c} > w_{a\text{-}c} > w_{a\text{-}b\text{-}c}$

P_{ext} = 9 kPa

CALCULATION OF PV WORK



P_{ext} = 29 kPa

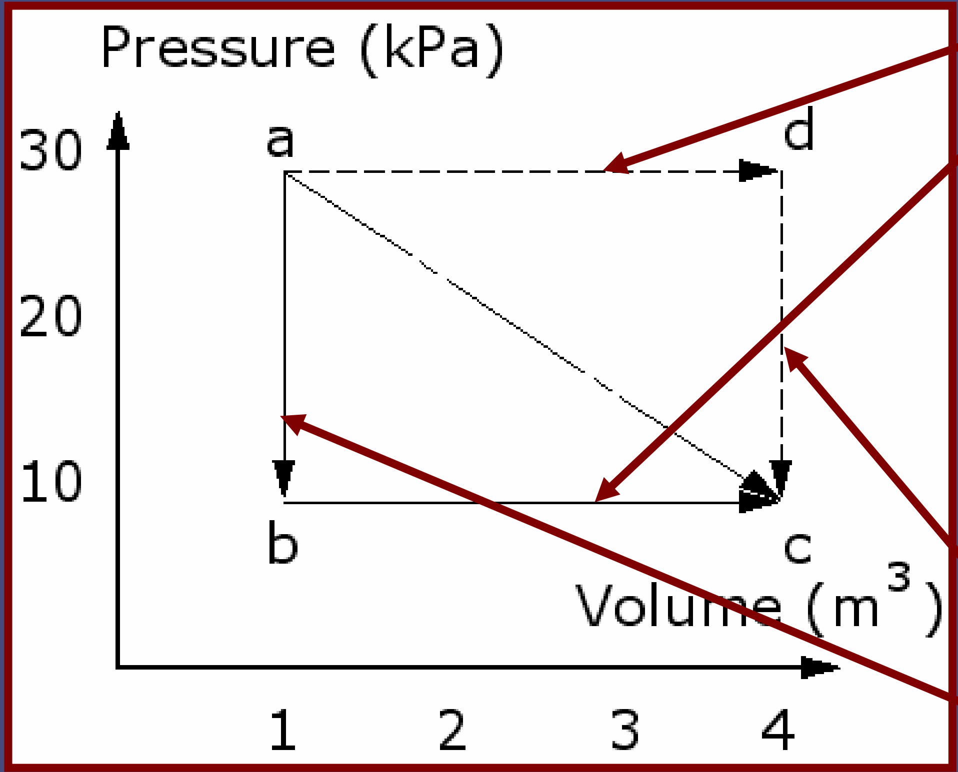
$w_{a\text{-}d\text{-}c} = w_{a\text{-}d}$
$= -P_{ad} \times (V_d - V_a)$
$= -29 \text{ kPa} \times (4 - 1) \text{ m}^3$
$= -87 \text{ kJ}$

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

P_{ext} = 9 kPa

PV DIAGRAMS

P CONSTANT & n CONSTANT & V INCREASES –> T INCREASES



PV = nRT
PV/nR = T

P DECREASES & n CONSTANT & V CONSTANT –> T DECREASES

CALCULATION OF PV WORK

RELATING q, w, P, V, AND T

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

ANSWER TOMORROW.

CALCULATION OF PV WORK

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

THE EQUATION OF STATE IS A MATHEMATICAL RELATIONSHIP AMONG P, V, T, AND n.

IDEAL GAS EQUATION OF STATE

$PV = nRT$ OR $PV/nR = T$ OR $nRT/V = P$

VAN DER WAALS EQUATION OF STATE

$[P + a(n^2/V^2)][V - nb]/nR = T$

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)

THERMODYNAMICS

THERMO (HEAT) AND DYNAMICS (WORK)

$$q \longleftrightarrow w$$

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.

CHEMICAL THERMODYNAMICS

THERMOCHEMISTRY IS CHEMICAL THERMODYNAMICS

- 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.

CHEMICAL THERMODYNAMICS

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 <u>FROM/TO</u> THE CHEMICAL SAMPLE <u>TO/FROM</u> THE WATER.

CHEMICAL THERMODYNAMICS

THE CALORIMETER