Chapter 5
Thermochemistry

The *energy* of chemical reactions

How do you keep track of it?
Where does it come from?

Energy

- The ability to:
- do work
- transfer heat.
  - Work: Energy used to cause an object that has mass to move.
  - Heat: Energy used to cause the temperature of an object to rise.

Units of Energy

- The SI unit of energy is the joule (J).

$$1\ \mathrm{J} = 1\ \frac{\mathrm{kg\ m^2}}{\mathrm{s^2}}$$

- An older, non-SI unit is still in widespread use: The calorie (cal).

$$1\ \mathrm{cal} = 4.184\ \mathrm{J}$$

Energy has units of (mass)(velocity)^2

Remember kinetic energy was $1/2mv^2$

Work

- Energy used to move an object over some distance.
- $w = F \cdot d$,

w = work,

F = force

d = distance over which the force is exerted.

Note units:

$F = ma$, mass(distance/s^2)

$W = F(d)$ = mass(distance^2/s^2)

$= mv^2$

(a)

(b)

Heat

- Energy can also be transferred as heat.
- Heat flows from warmer objects to cooler objects.

Kinetic Energy

Energy an object possesses by virtue of its motion.

$$KE = \frac{1}{2}mv^2$$

Potential Energy

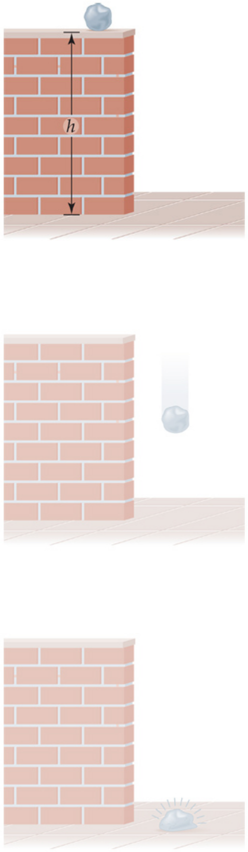
Energy an object possesses by virtue of its position or chemical composition.

More potential E

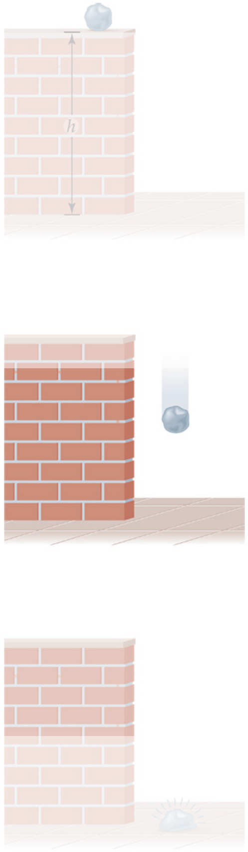
Less P.E. as bike goes down.

Transferal of Energy

a) Add P.E. to a ball by lifting it to the top of the wall



Transferal of Energy



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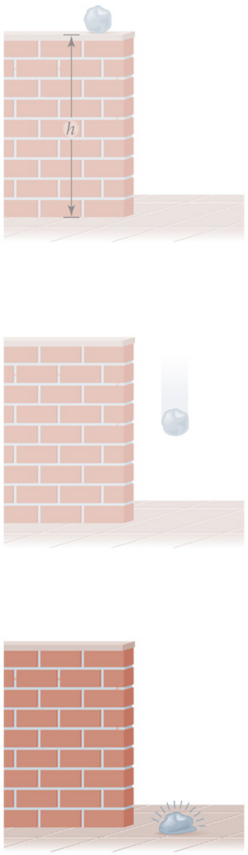
b) As the ball falls,

P.E ------> K. E. $(1/2mv^2)$

Transferal of Energy



a) Add P.E. to a ball by lifting it to the top of the wall

b) As the ball falls,

P.E ------> K. E. ($1/2mv^2$)

Ball hits ground, K.E. =0, but E has to go somewhere. So

1. Ball gets squashed
2. Heat comes out.

Energy accounting

- We must identify where different types of energy go.

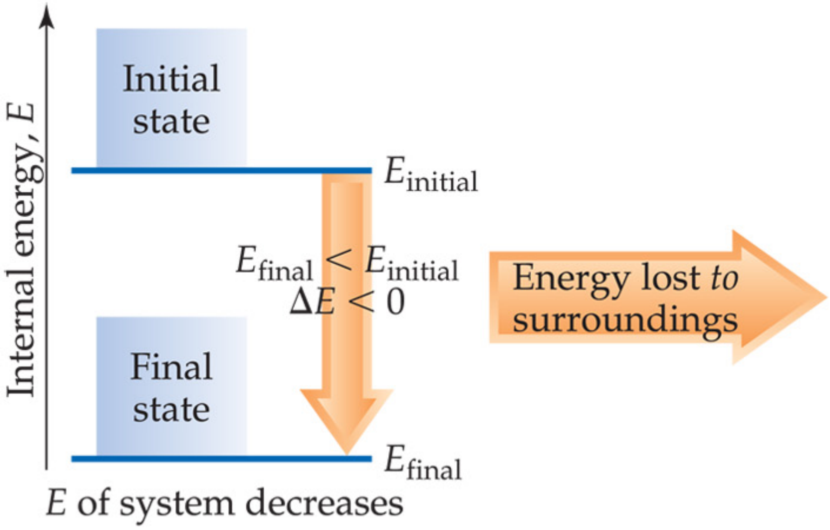
- Therefore, we must identify the *places.*

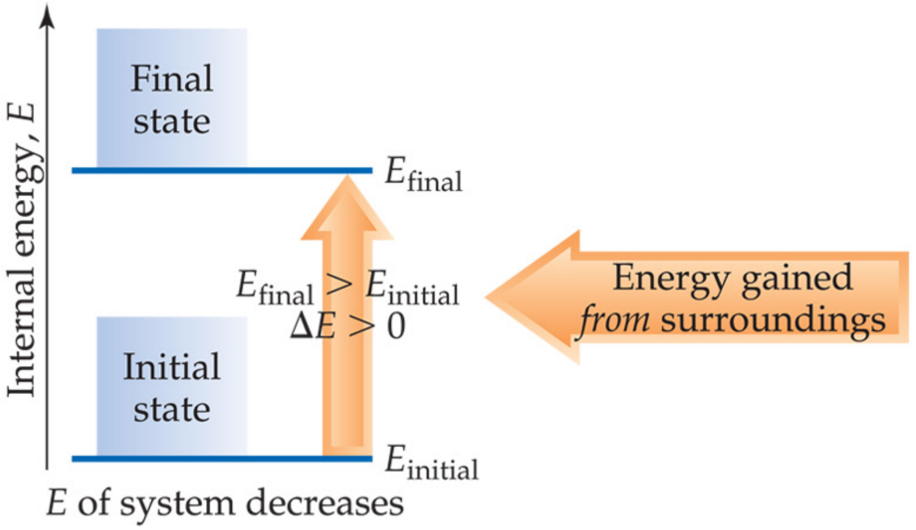
System and Surroundings

- The system includes the molecules we want to study (here, the hydrogen and oxygen molecules).
- The surroundings are everything else (here, the cylinder and piston).

First Law of Thermodynamics

- Energy is conserved.
- In other words, the total energy of the universe is a constant; $\Delta E_{System} = -\Lambda E_{surroundings}$





Internal Energy

The internal energy of a system is the sum of all kinetic and potential energies of all components of the system; we call it *E.*

$$E_{\text{internal,total}} = E_{KE} + E_{PE} + E_{\text{electrons}} + E_{\text{nuclei}} + \ldots\ldots$$

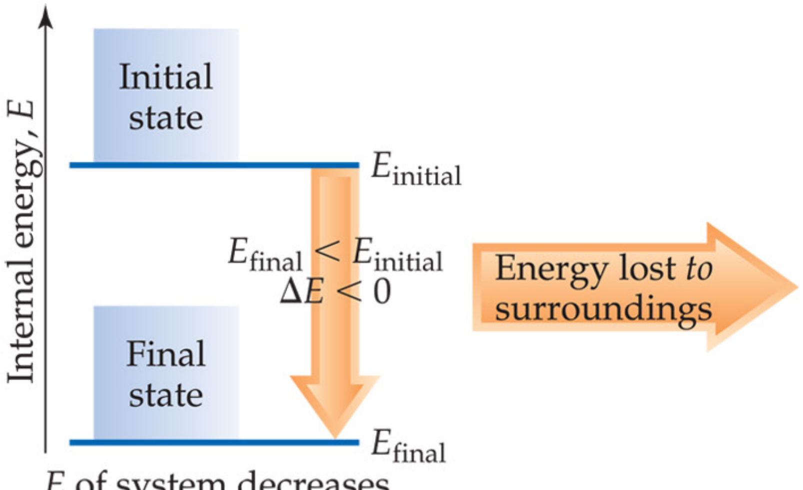
Almost impossible to calculate total internal energy

Instead we always look at the ***change*** in energy (ΔE).

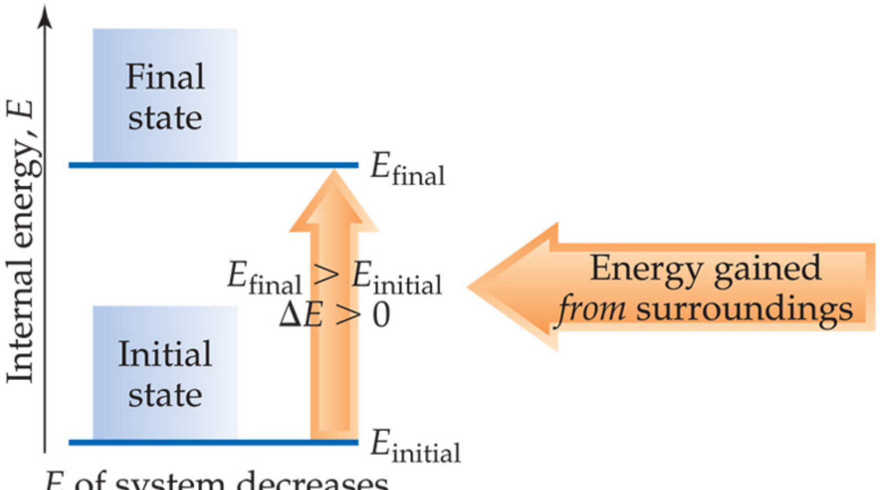
Internal Energy

By definition, the change in internal energy, ΔE, is the final energy of the system minus the initial energy of the system:

$$\Delta E = E_{\text{final}} - E_{\text{initial}}$$

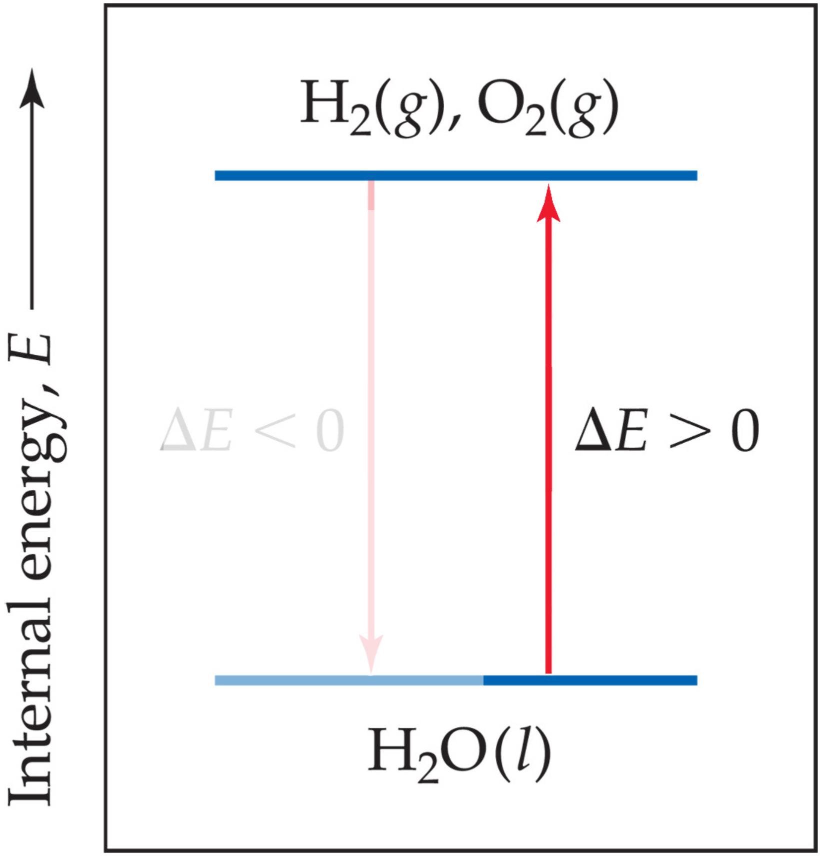


E of system decreases



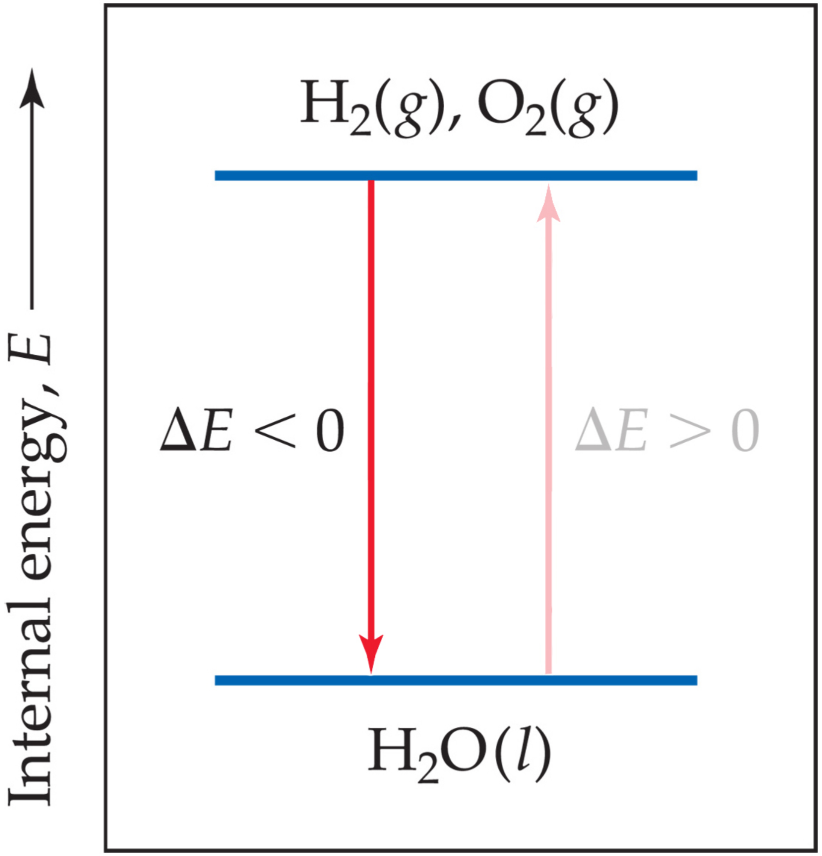
E of system decreases

Changes in Internal Energy



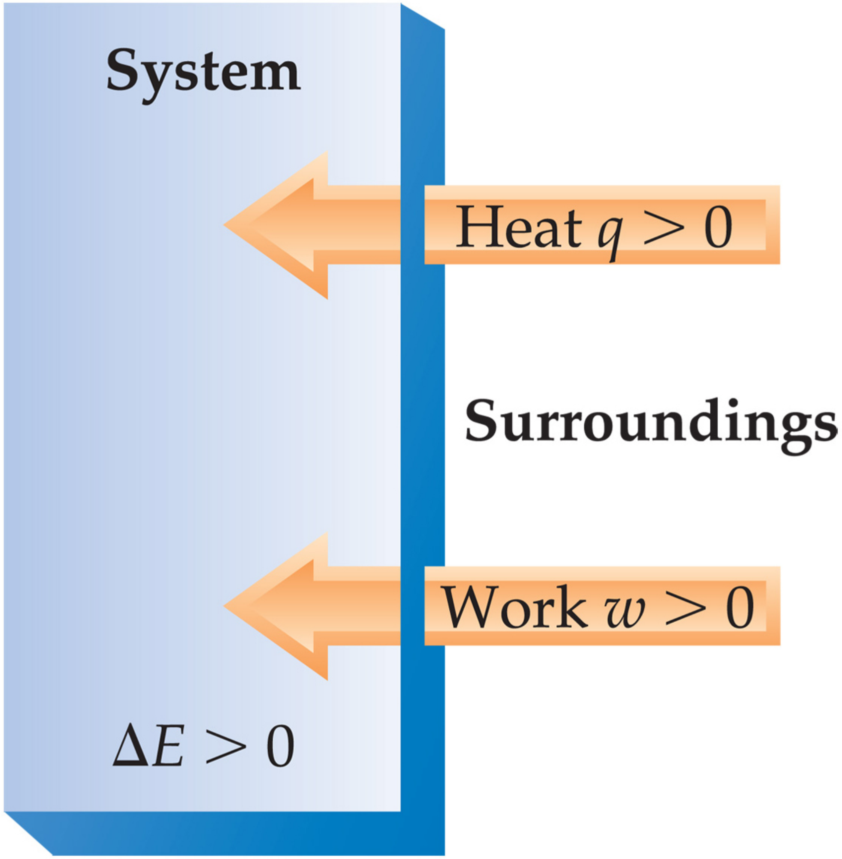
- If $\Delta E > 0$, $E_{\text{final}} > E_{\text{initial}}$
  - Therefore, the system *absorbed* energy from the surroundings.
  - This energy change is called **endergonic.**

Changes in Internal Energy



- If $\Delta E < 0$, $E_{\text{final}} < E_{\text{initial}}$
  - Therefore, the system *released* energy to the surroundings.
  - This energy change is called **exergonic.**

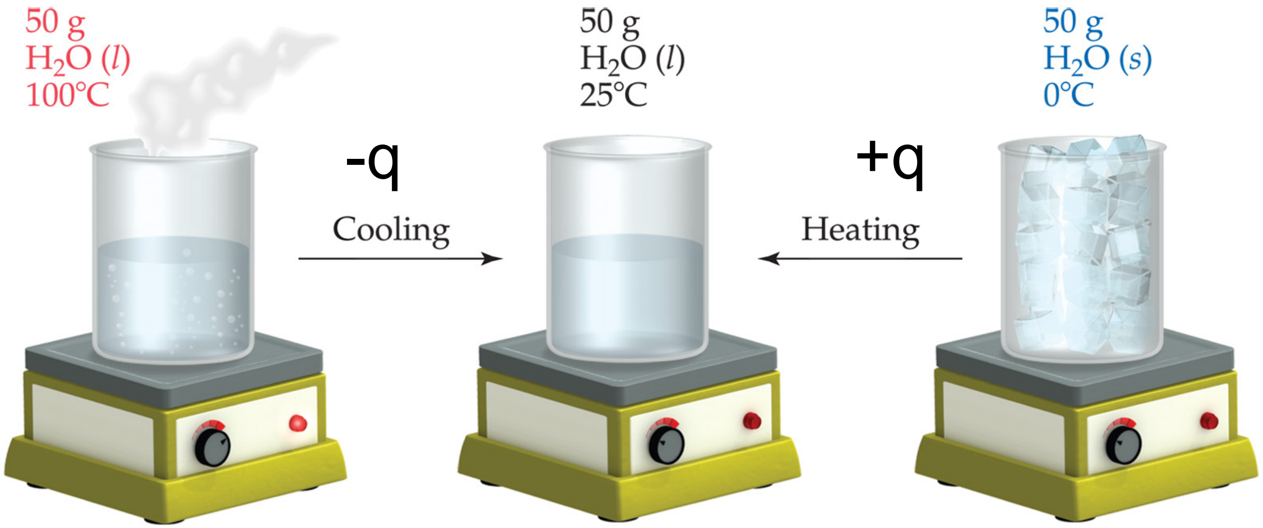
Changes in Internal Energy



- When energy is exchanged between the system and the surroundings, it is exchanged as either heat (*q*) or work (*w*).
- That is, $\Delta E = q + w$.

ΔE, q, w, and Their Signs

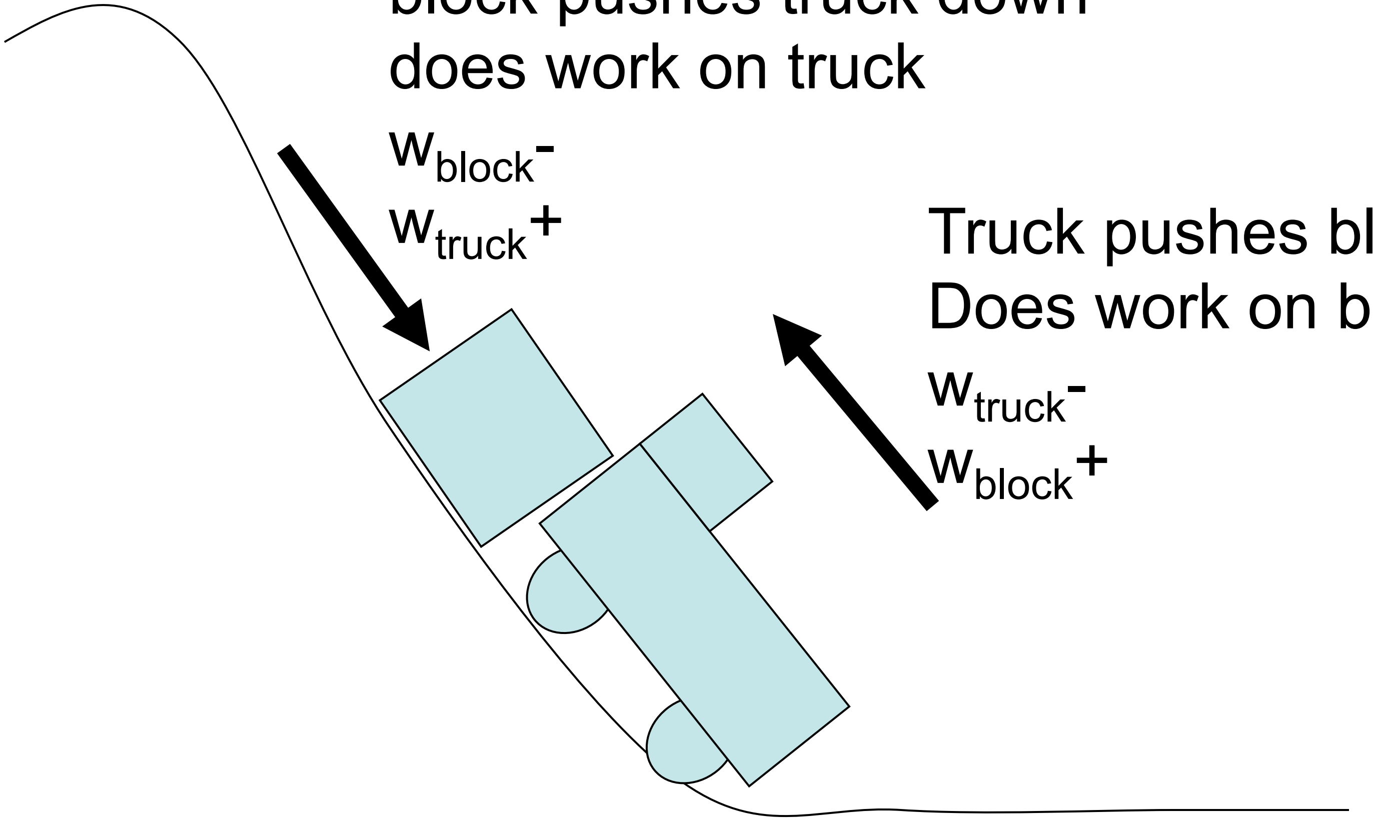
For q	+ means system *gains* heat	− means system *loses* heat
For w	+ means work done *on* system	− means work done *by* system
For ΔE	+ means *net gain* of energy by system	− means *net loss* of energy by system



Surroundings suck heat out of water.

hot plate adds heat to water

Sign of work



block pushes truck down
does work on truck

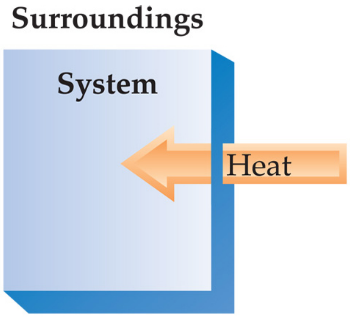
w_{block} -
w_{truck} +

Truck pushes block up.
Does work on block

w_{truck} -
w_{block} +

Exchange of Heat between System and Surroundings

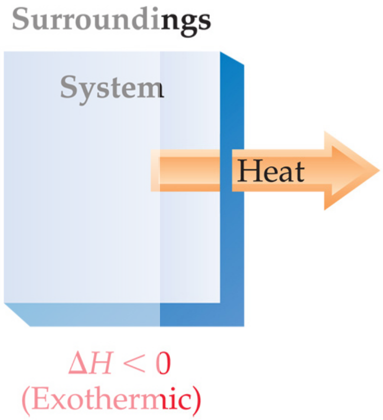
- When heat is absorbed by the system from the surroundings, the process is endothermic.



$\Delta H > 0$
(Endothermic)

Exchange of Heat between System and Surroundings

- Heat absorbed by system from surroundings, is ***endothermic***.
- Heat released by system to surroundings, the is ***exothermic***.

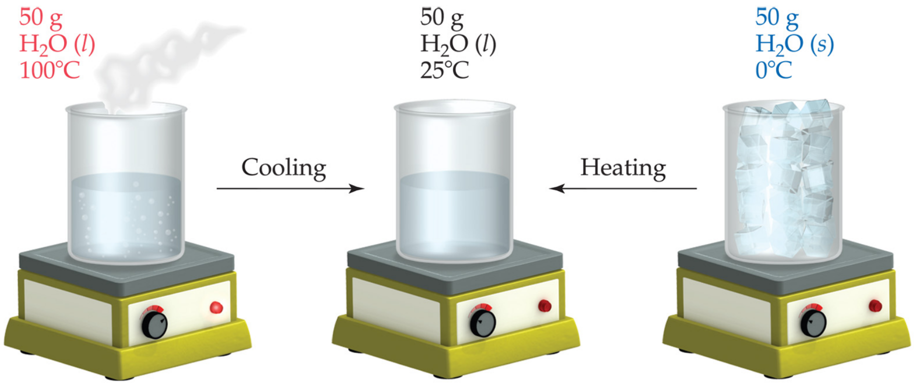


State Functions

Total internal energy of a system:

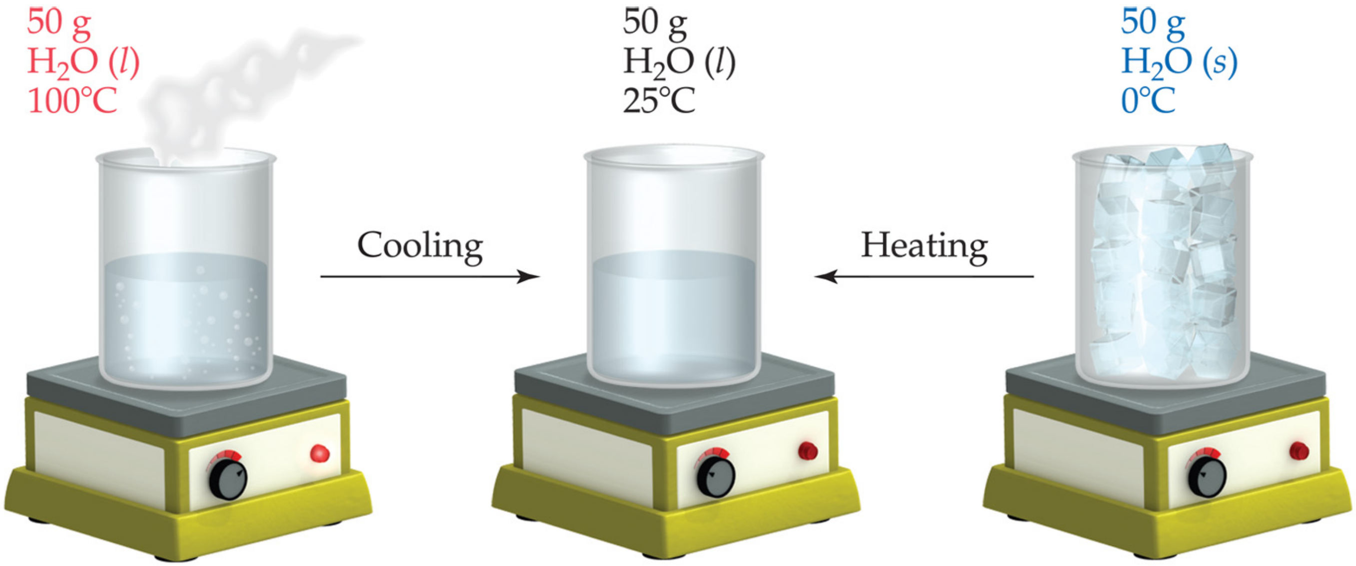
K.E. + $E_{electrons}$ + $E_{nucleus}$ + $P.E._{total}$

virtually impossible to measure/calculate



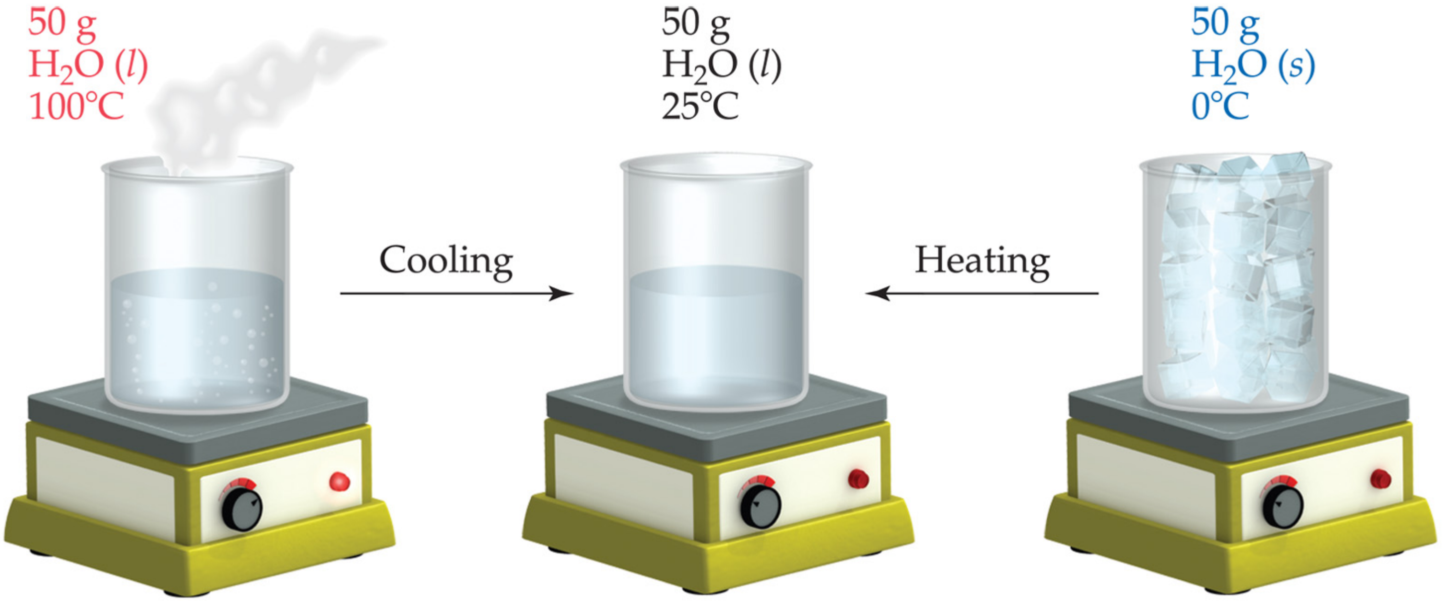
State Functions

- However, we do know that the internal energy of a system is independent of the path by which the system achieved that state.
  - In the system below, the water could have reached room temperature from either direction.

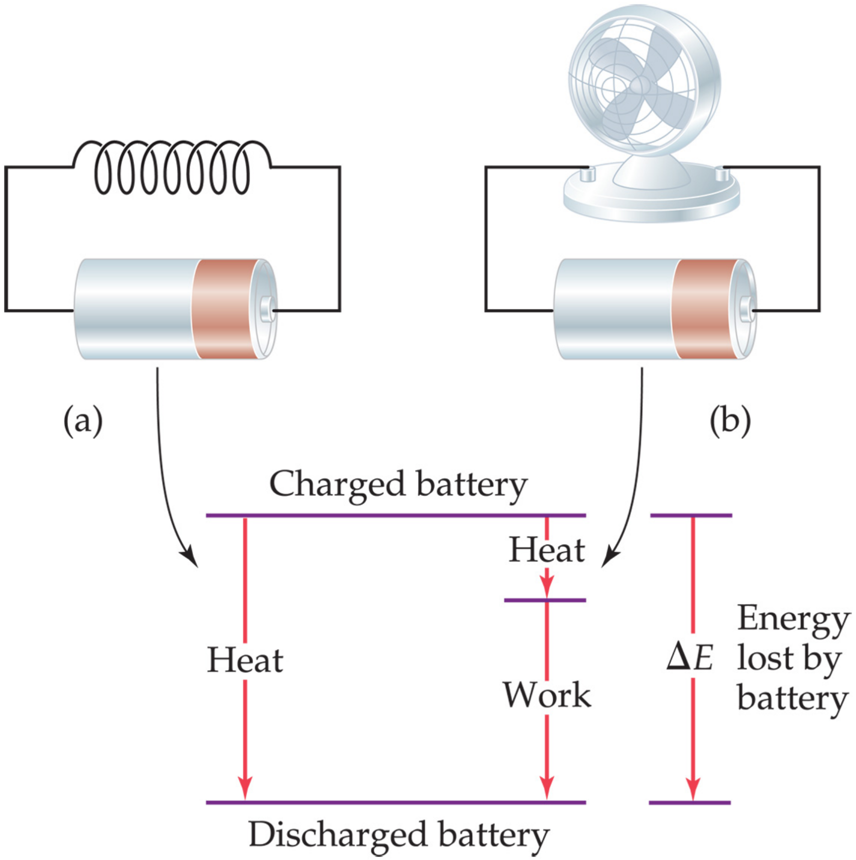


State Functions

- Therefore, internal energy is a state function.
- because it’ s PATH INDEPENDENT
- And so, ΔE depends only on E_{initial} and E_{final}.

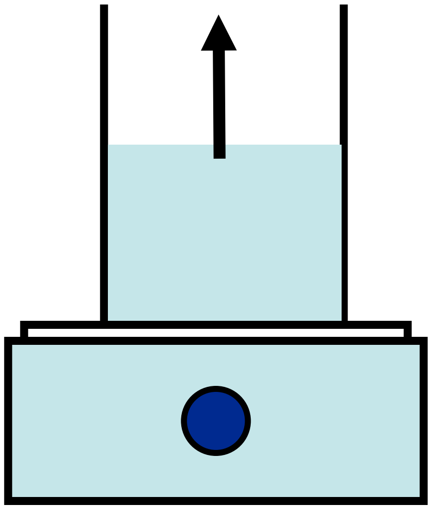


State Functions



- However, *q* and *w* are **not** state functions.
- Whether the battery is shorted out or is discharged by running the fan, its ΔE is the same.
  - But *q* and *w* are different in the two cases.

Work

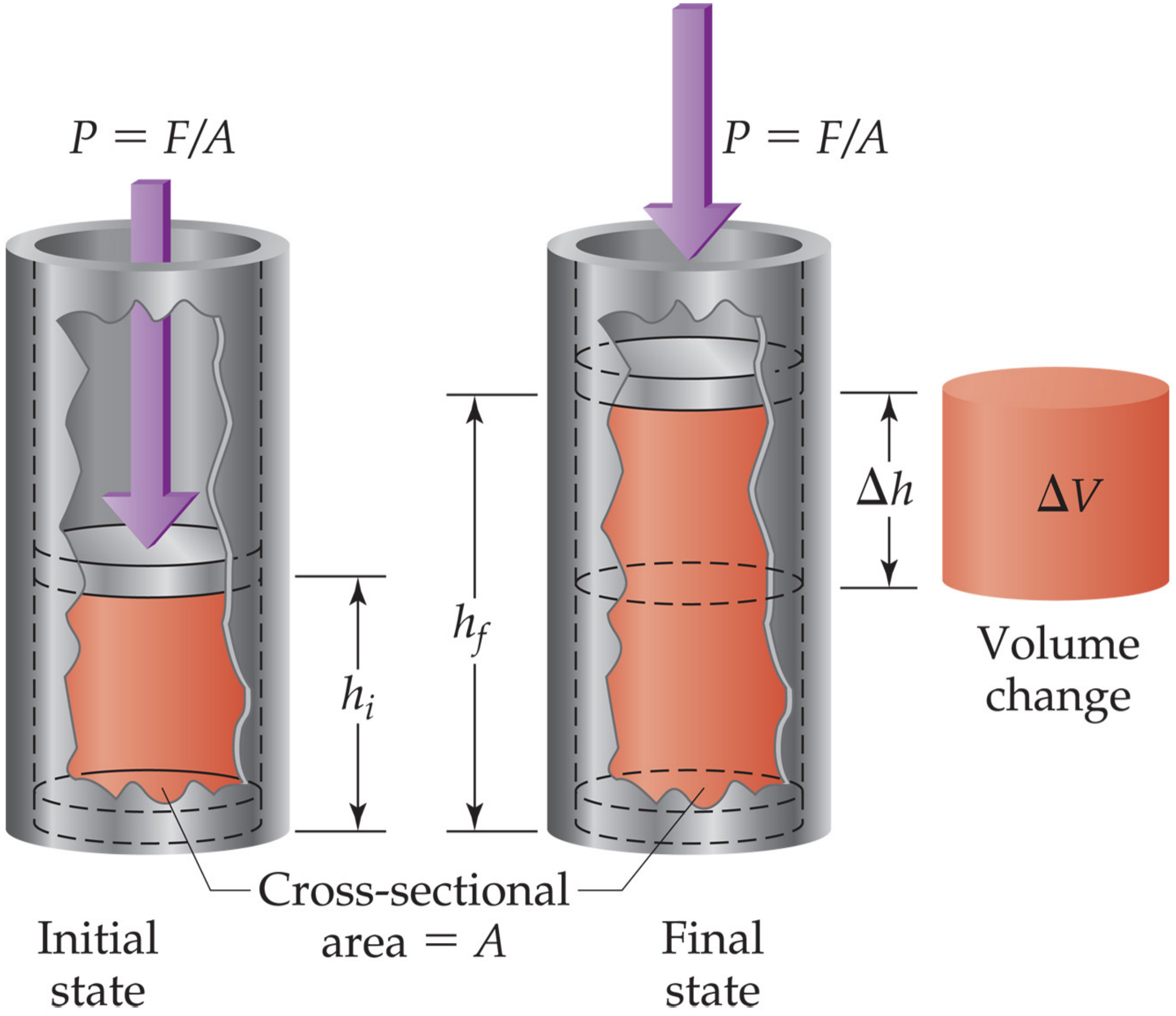


process in an open container (chemical reaction in a beaker)

w? (can there be any work)?

Yes, evolving gases could push on the surroundings.

Catch the work, do the same process in a cylinder



Process evolves gas, pushes on piston, work done on piston

Catch the work, do the same process in a cylinder

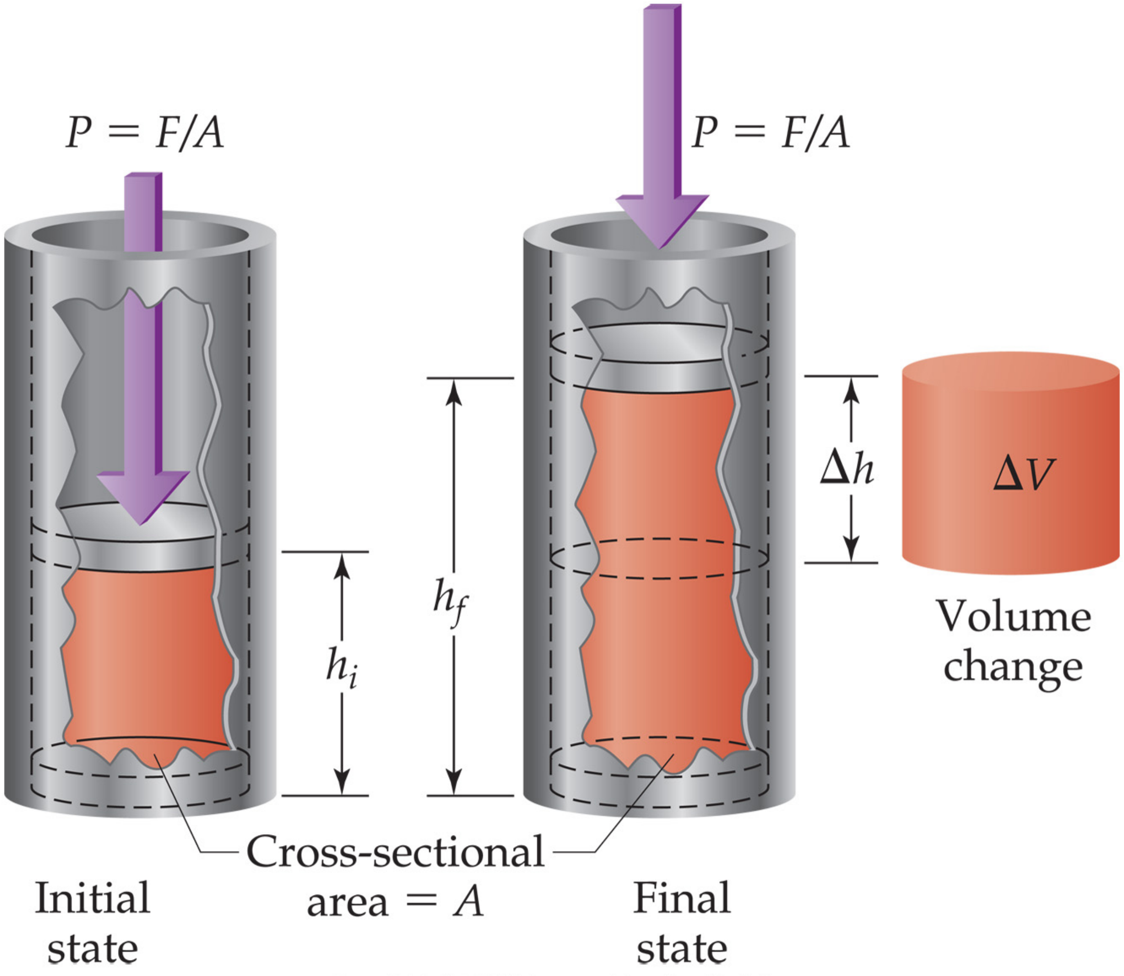
w = F*d, F = P*A, d=Δh

w = -P*AΔh= -PΔV

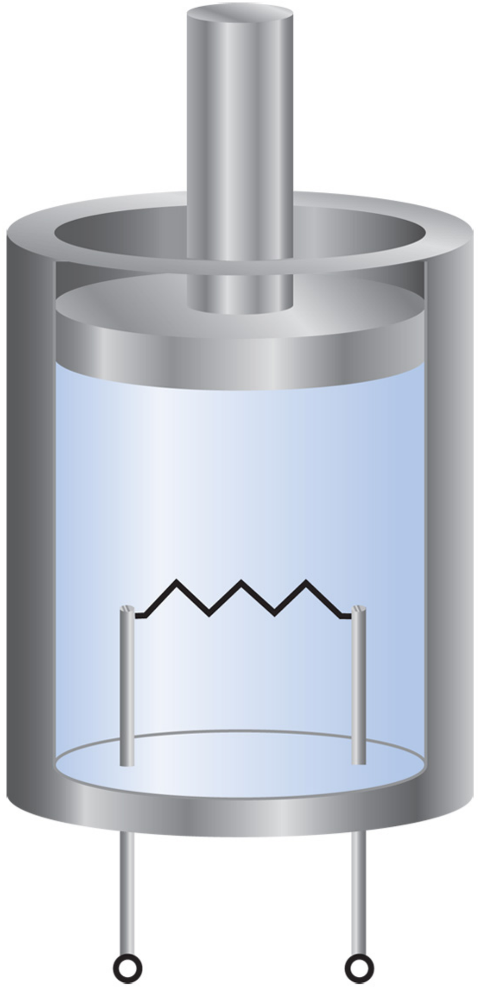
Negative because an ***increase*** in Volume means that the system is doing work ***on*** the surroundings.

$$\Delta E = q + w = q - P\Delta V$$

$$q_P = \Delta E + P\Delta V$$



Example



- Gas inside cylinder with electric heater.
- Add 100 j heat with heater.
- 1. Piston can go up and down
- 2. Piston stuck.
- a. What happens to T in each case?
- b. What about q and w for each case?
- c. What about ΔE in each case?

Example

- Gas inside cyclinder with electric heater.
- Add 100 j heat with heater.
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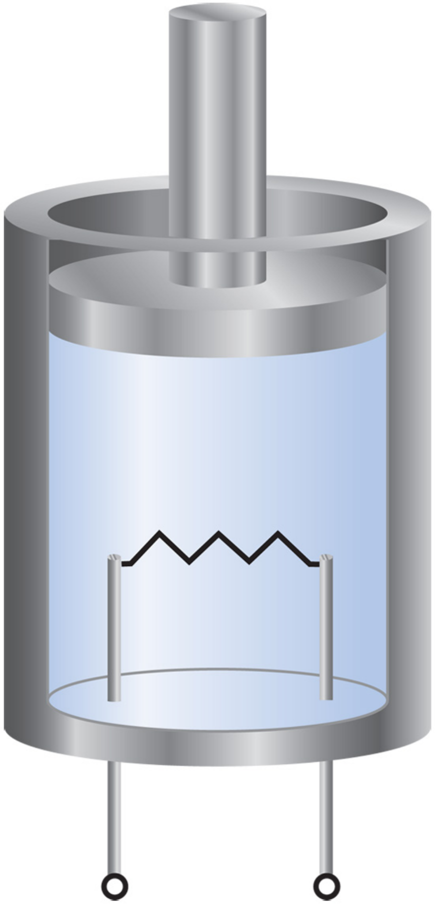


a.1. Piston goes up, some E goes to expand gas, do work. T goes up less

a.2 T goes up more, all E goes to q.

b.1. both q and w positive

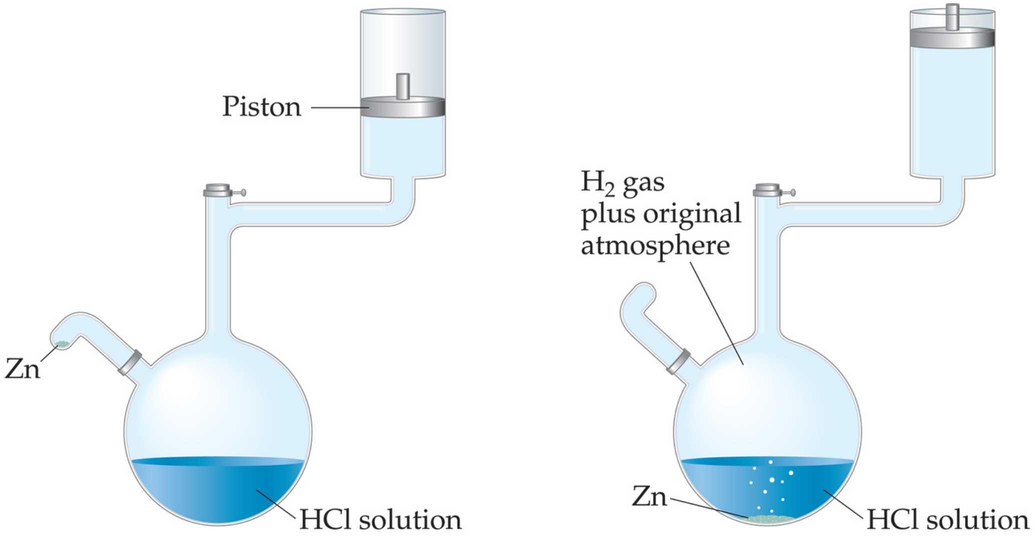
b.2. w 0, q larger

c. ΔE the same & + in each case

Work

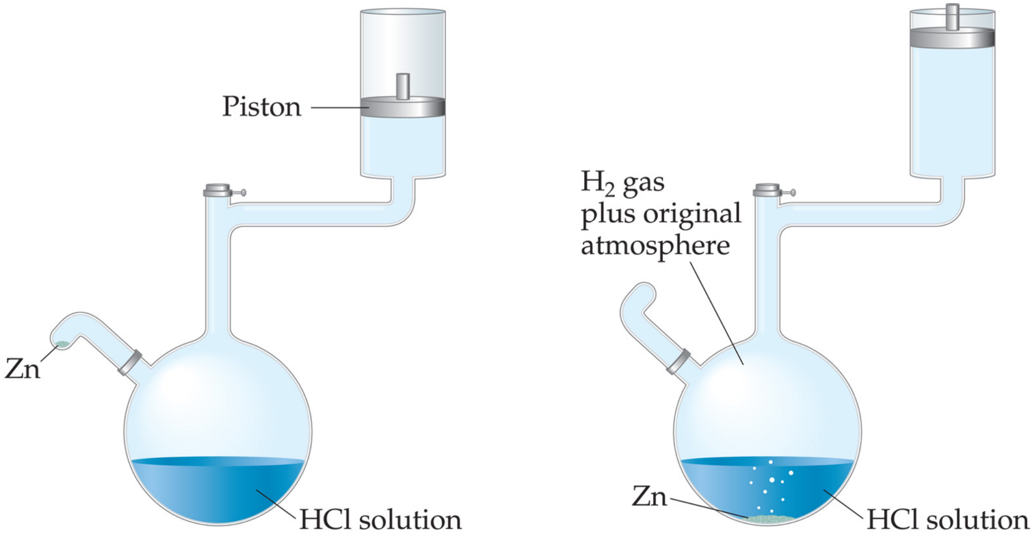
Now we can measure the work:

$$w = -P\Delta V$$



$Zn + 2HCl$ ---------> $H_{2(g)} + ZnCl_2$

Work

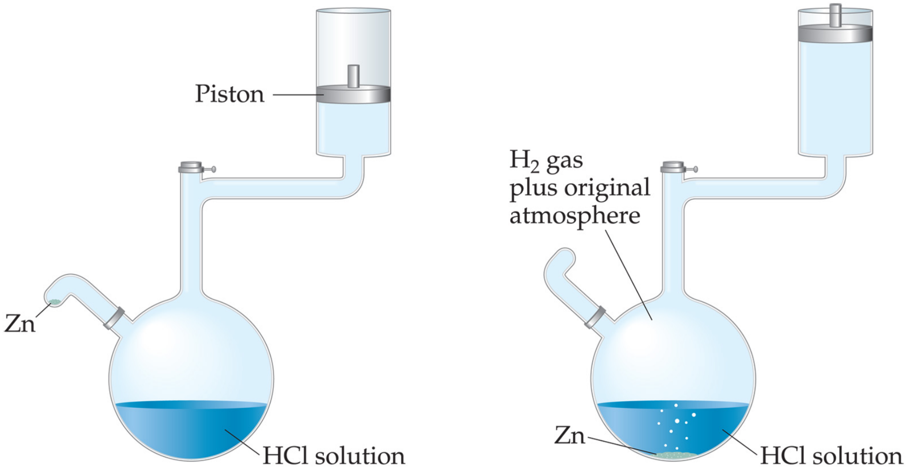


$Zn + 2HCl$ ---------> $H_{2(g)} + ZnCl_2$

I mole of Zn reacts. How much work is done (P = 1 atm, density of H_2 = 0.0823 g/L)?

1 mole of H_2 is produced.

Work



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1 mole of H_2 is produced.

Zn + 2HCl ---------> $H_{2(g)}$ + $ZnCl_2$

1mol 1 mol

2. 014 g/mol

2.014 g

d=m/V

V=m/d

V = 2.014g/0.0823g/L = 24.47 L

W = -PΔV = 1atm(24.47L) = -24.47 L(atm)

Enthalpy(H)

$$H = E + PV$$

This is the definition of Enthalpy for *any* process
Buy why do we care?

Enthalpy

$$H = E + PV$$

- at constant pressure, ΔH, is

(Δ = change in thermodynamics)

$$\Delta H = \Delta(E + PV)$$

- This can be written (if P constant)

$$\Delta H = \Delta E + P\Delta V$$

Enthalpy

- Since $\Delta E = q + w$ and $w = -P\Delta V$ *(P const.)* substitute these into the enthalpy expression:

$$\Delta H = \Delta E + P\Delta V$$

$$\Delta H = (q+w) - w$$

$$\Delta H = q$$

- **Note: true at constant pressure**
- q is a state function at const P & only PV work.

$H = E + PV$

- **Because:**
- If pressure is constant (like open to atmosphere, i.e. most things) and

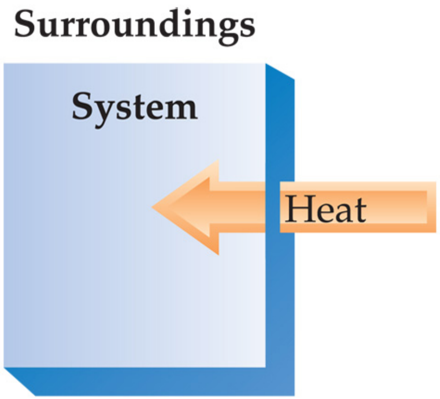
w = ΔPV.

heat flow (q) = H (enthalpy) of system.

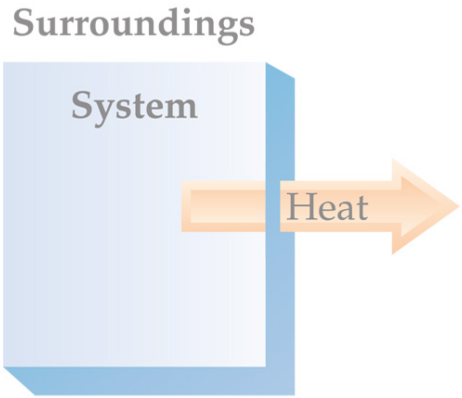
And: H is a state function, so q is also.

but only in the right conditions

Endothermic vs. Exothermic



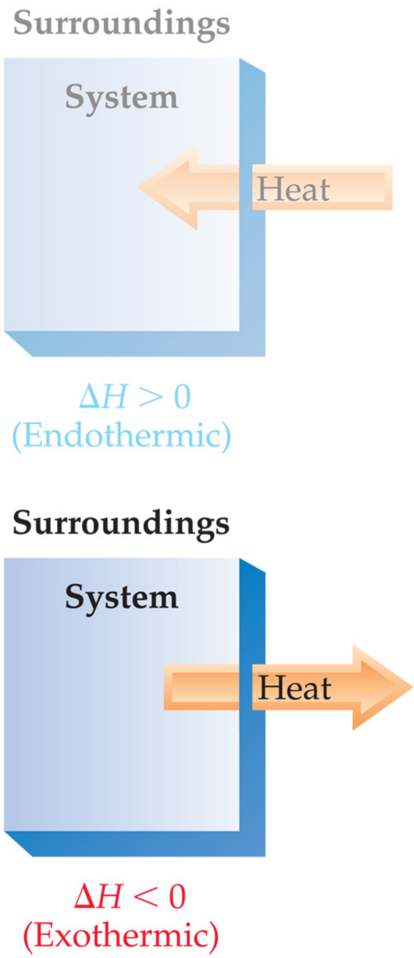
$\Delta H > 0$
(Endothermic)



$\Delta H < 0$
(Exothermic)

- A process is endothermic when ΔH is positive.

Endothermicity and Exothermicity

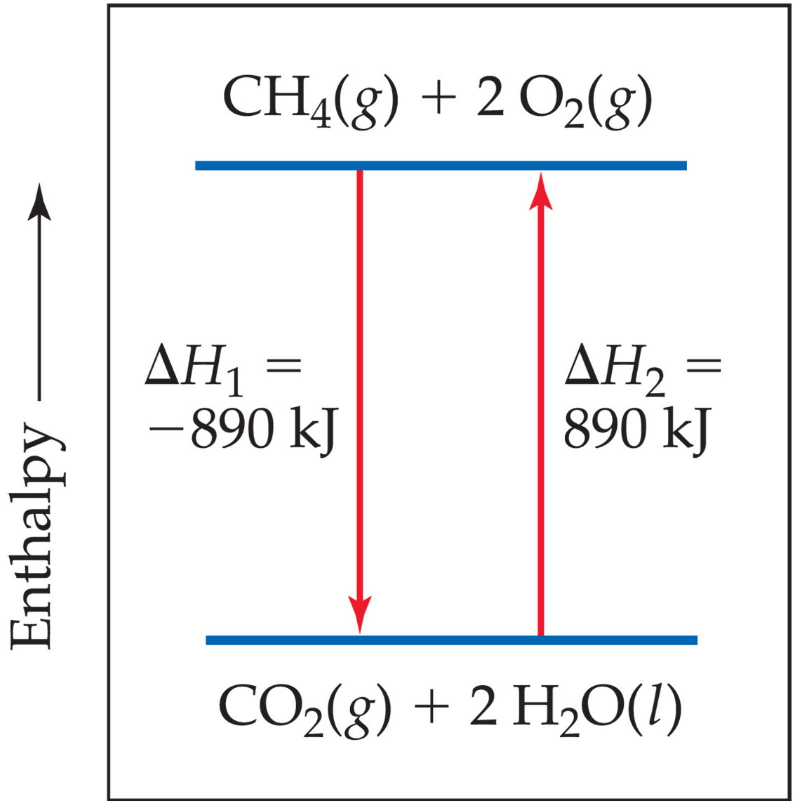


- A process is endothermic when ΔH is positive.
- A process is exothermic when ΔH is negative.

Enthalpies of Reaction

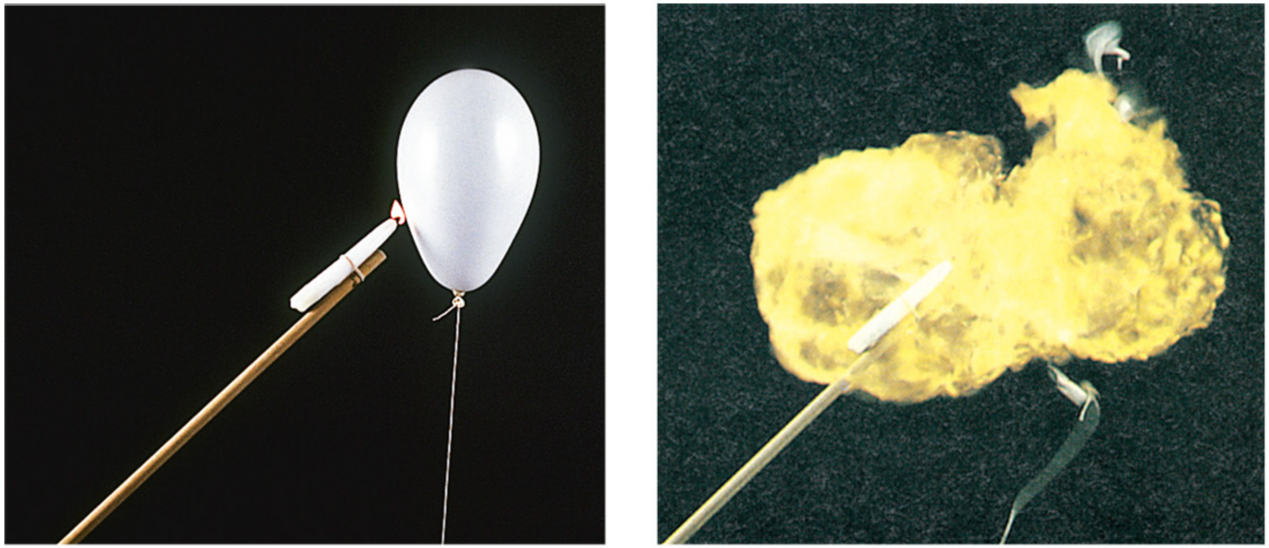
The *change* in enthalpy, ΔH, is the enthalpy of the products minus the enthalpy of the reactants:

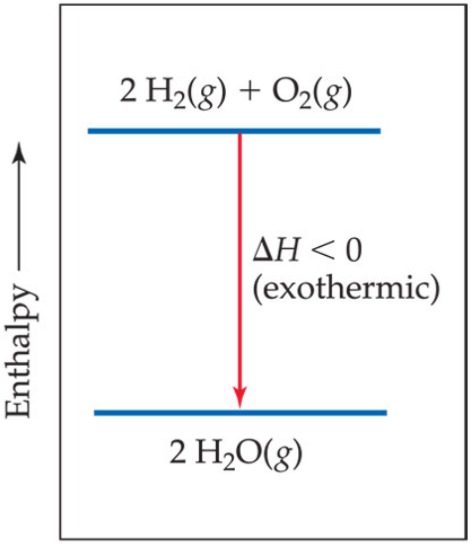
$$\Delta H = H_{\text{products}} - H_{\text{reactants}}$$



Enthalpies of Reaction

This quantity, ΔH, is called the enthalpy of reaction, or the heat of reaction.





Reaction Enthalpy summary

1. Enthalpy is an extensive property.
2. ΔH for a reaction in the forward direction is equal in size, but opposite in sign, to ΔH for the reverse reaction.
3. ΔH for a reaction depends on the state of the products and the state of the reactants.

Enthalpy of reaction example

Consider the reaction:

$2KClO_3$ -------> $2KCl + 3O_2$ $\Delta H = -89.4$ kJ/mol

a. What is the enthalpy change for formation of 0.855 moles of O_2?

Enthalpy of reaction example

Consider the reaction:

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a. What is the enthalpy change for formation of 0.855 moles of O_2?

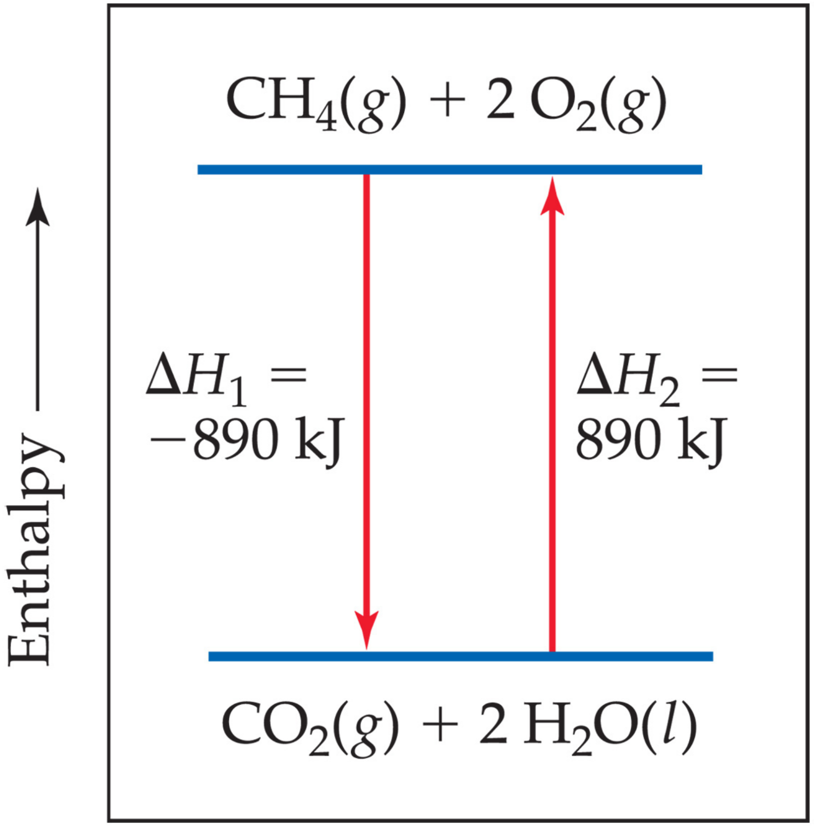
$2KClO_3$ -------> $2KCl$ + $3O_2$ $\Delta H = -89.4$ kJ/mol

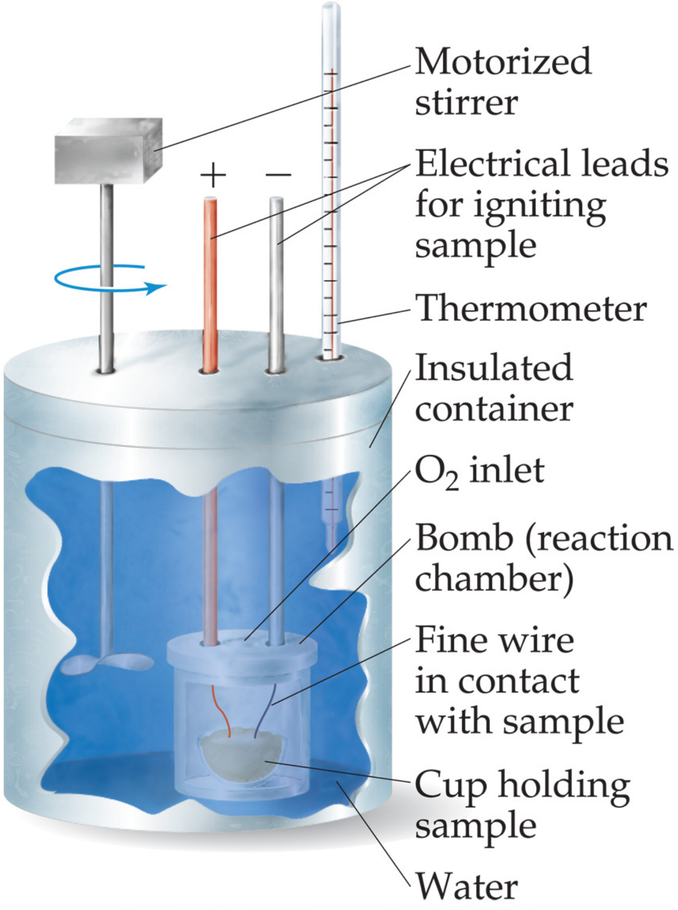
0.855 mol

$\Delta H = -89.4$ kJ/3 mol O_2(.855 mol O_2) =

-25.5 kJ

Calorimetry





Since we cannot know the exact enthalpy of the reactants and products,

we measure ΔH through calorimetry, the measurement of heat flow.

Heat Capacity and Specific Heat

- **heat capacity:** amount of E required to raise the temperature of something by 1 K
- **specific heat:** amount of E required to raise the temperature of 1 g of a substance by 1 K.

Heat Capacity and Specific Heat

Specific heat is:

$$\text{Specific heat} = \frac{\text{heat transferred}}{\text{mass} \times \text{temperature change}}$$

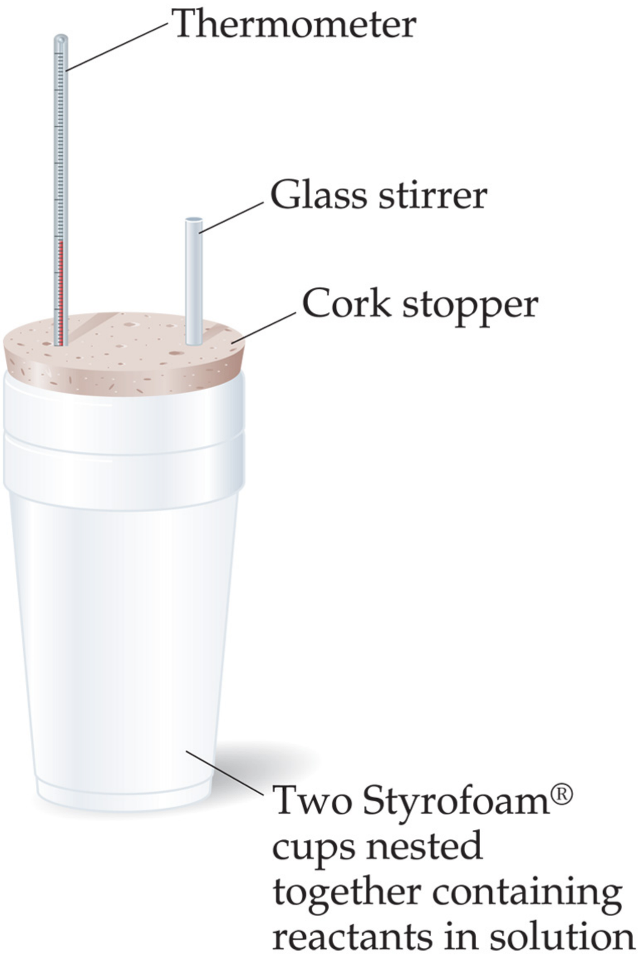
$$s = \frac{q}{m\,\Delta T}$$

$$sm\Delta T = q$$

Constant Pressure Calorimetry

indirectly measure the heat change for the system by measuring the heat change for the water in the calorimeter.

Constant Pressure Calorimetry



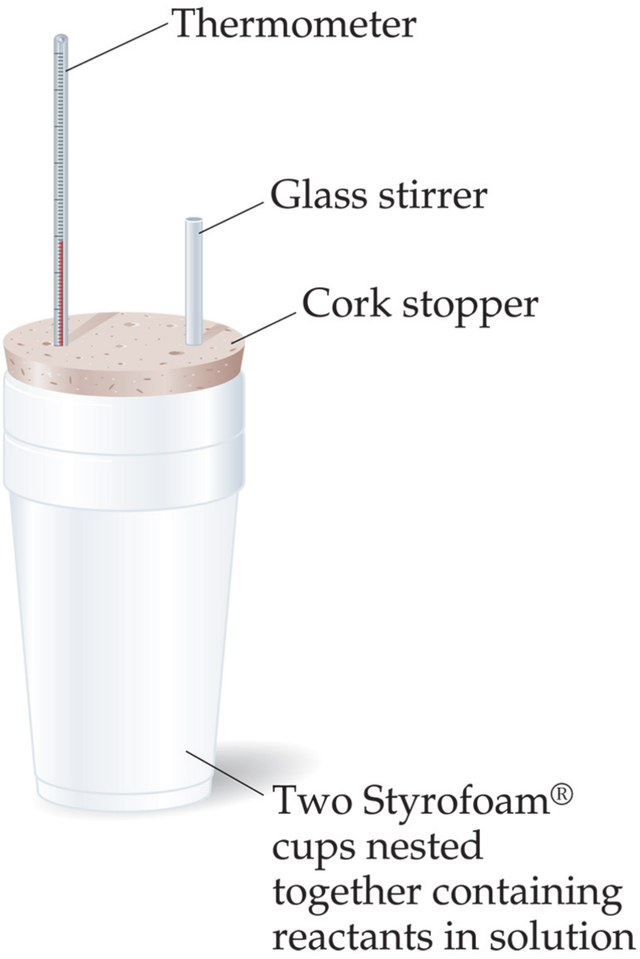
Because the specific heat for water is well known (4.184 J/g-K), we can measure ΔH for the reaction with this equation:

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

m = mass

s = specific heat

Example



When a 3.88 g sample of solid ammonium nitrate disolves in 60.0 g of water in a coffee cup calorimeter, the temperature drops from 23.0 °C to 18.4 °C. (a) Calculate ΔH (in kJ/mol ammonium nitrate) for the solution process. Assume that the specific heat is constant and = 1.0 cal/gC. (b) Is this process endothermic or exothermic?

Example

When a 3.88 g sample of solid ammonium nitrate disolves in 60.0 g of water in a coffee cup calorimeter, the temperature drops from 23.0 °C to 18.4 °C. (a) Calculate ΔH (in kJ/mol ammonium nitrate) for the solution process. Assume that the specific heat is constant and = 4.184 J/g°C. (b) Is this process endothermic or exothermic?

Reaction:

	$NH_4NO_3(s)$ ------> $NH_4^+(aq) + NO_3^-(aq)$
gr	3.88 g
MW	80.04 g/mol
#Mol	3.88 g/80.04 g/mol = 0.0484 mol

Mass of solution = 3.88 g + 60 g = 63.88 g.

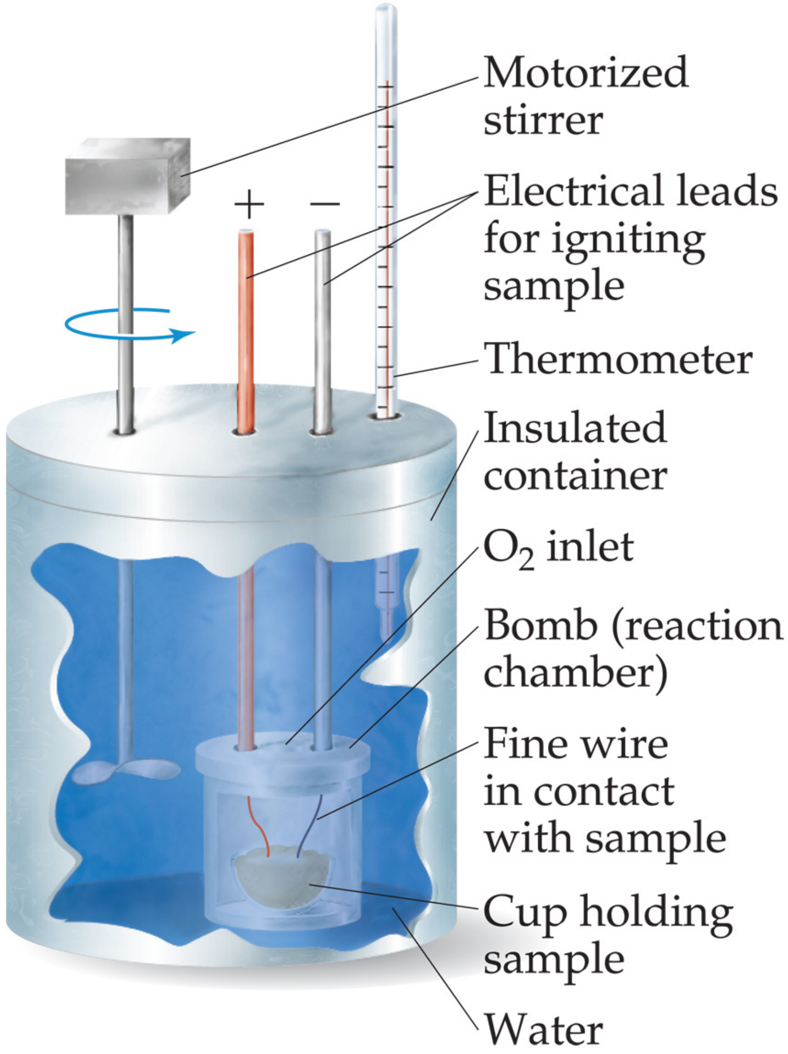
System: Solid $AmNO_3$
Surroundings: Solution

$q = s(\text{specific heat})m(\text{mass})\Delta T$
$q = s(J/g°C)m(\text{grams})(T_{\text{final}} - T_{\text{initial}})$
$q_{\text{solution}} = 4.184(J/g°C)(63.88\ g)(18.4°C - 23.0°C) = -1229\ J$
$q_{\text{water}} = -q_{\text{ammonium nitrate}} = +1229\ J$
$\Delta H(\text{per mol } NH_4NO_3) = 1.229\ kJ/.0484\ mol = 25.39\ kJ/mol$
(b) Endothermic

Bomb Calorimetry

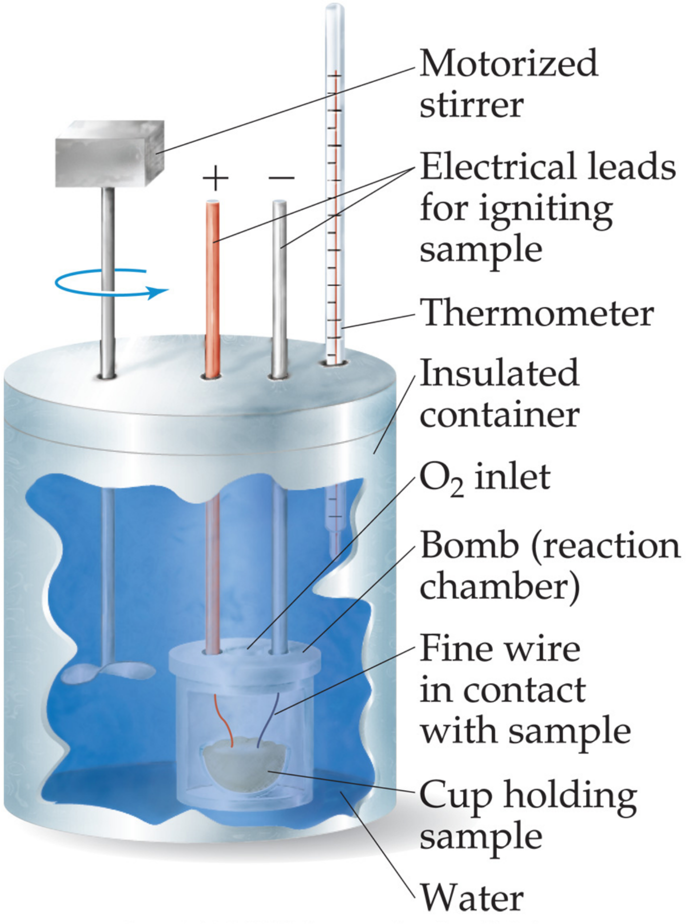
Reactions can be carried out separated from the water in a “bomb,” such as this one,

And still measure the heat absorbed by the water.



Bomb Calorimetry

- Because the volume in the bomb calorimeter is constant, what is measured is really the ΔE, not ΔH.
- For most reactions,
- $\Delta E \approx \Delta H$
- *Why?*



Bomb Calorimetry

$H = E + PV$

$\Delta H = \Delta E + \Delta PV$

In a bomb calorimeter, $\Delta V = 0$

For a process that doesn't evolve gas:

$\Delta P \approx 0$ as well.

$\Delta H = \Delta E + \Delta PV = \Delta E$

Example

- A 50 g sample of gasoline was burned by combustion (with excess oxygen) in a calorimeter with a heat capacity of 10 kJ/°C. The temperature increased by 100 °C. Calculate the change in E per g of gasoline.

- $q_{surroundings} = C\Delta T = 10$ kJ/°C(100 °C) = 1000 kJ
- $q_{surroundings} = -q_{system}$
- $q_{system} = -1000$
- -1000 kJ/50g = -20 kJ/g

- **Does** $\Delta E = \Delta H$ in this case?

Example

- A 50 g sample of gasoline was burned by combustion (with excess oxygen) in a calorimeter with a heat capacity of 10 kJ/°C. The temperature increased 100 °C. Calculate the change in E per g of gasoline.

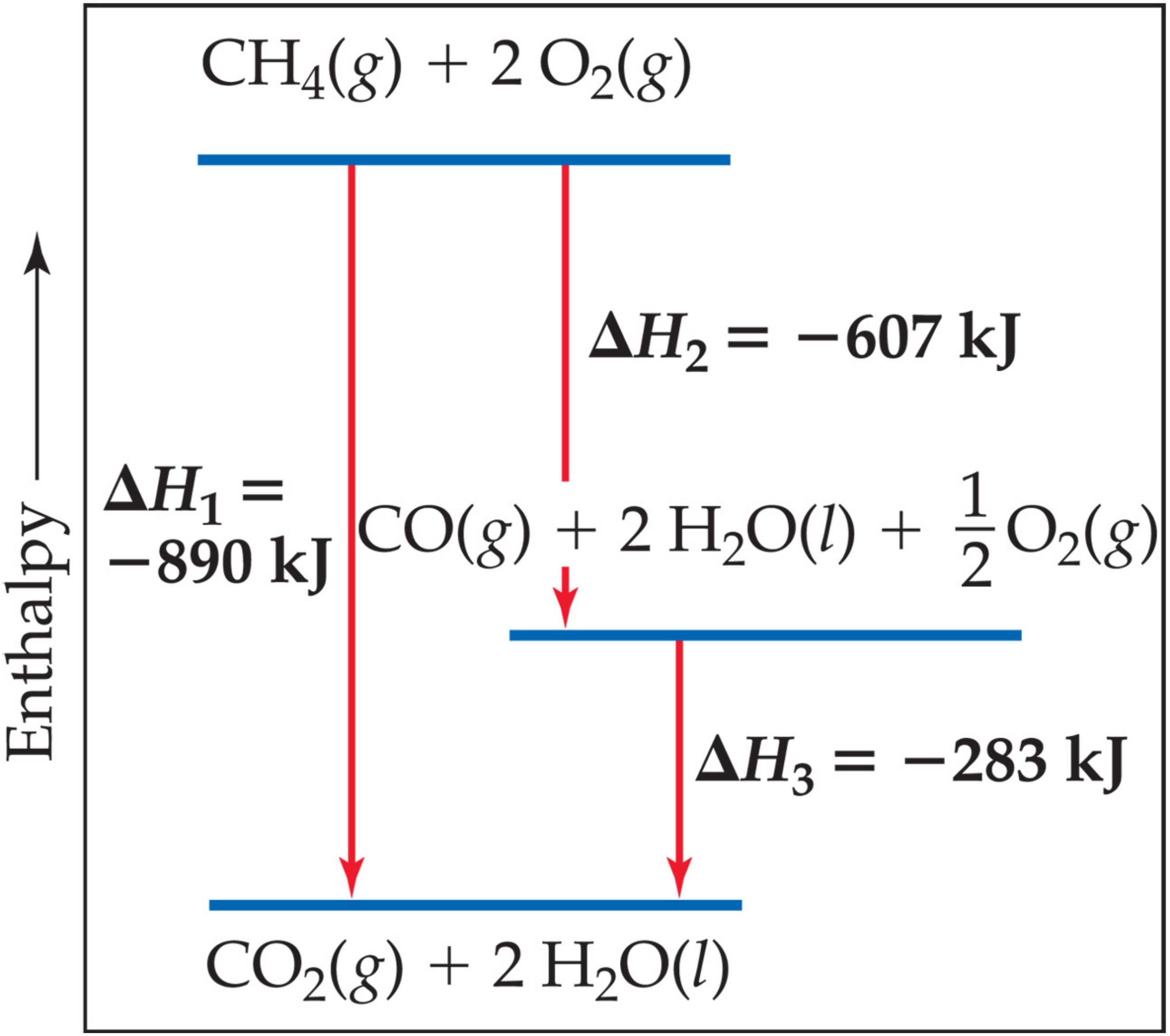
- $q_{surroundings} = C\Delta T = 10\ \text{kJ/°C}(100\ \text{°C}) = 1000\ \text{kJ}$
- $q_{surroundings} = -q_{system}$
- $q_{system} = -1000$
- $-1000\ \text{kJ}/50\text{g} = -20\ \text{kJ/g}$

- **Does** $\Delta E = \Delta H$ in this case?
- **NO! Pressure can't stay constant in this case.**

Hess's Law

- ΔH is known for many reactions.
- measuring ΔH can be a pain
- Can we estimate ΔH using ΔH values for other reactions?

Hess’ s Law

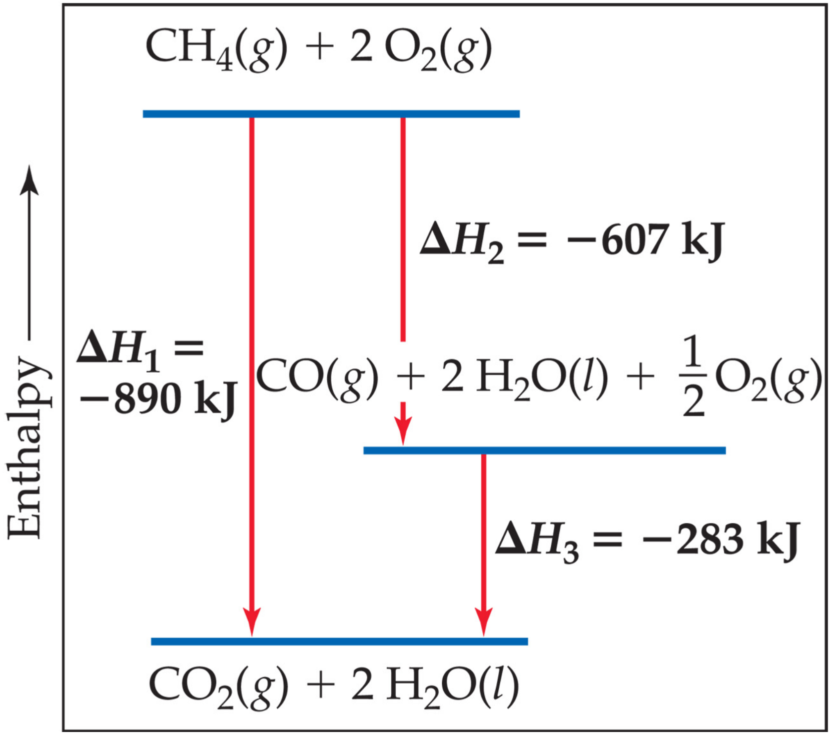


Yes!

Hess’ s law: states that:

ΔH for the overall reaction will be equal to the sum of the enthalpy changes for the individual steps.

Hess's Law



Why?

Because ΔH is a state function, and is pathway independent.

Only depends on initial state of the reactants and the final state of the products.

Hess' s law, example:

- Given:
- $N_2(g) + O_2(g)$ ----> $2NO(g)$ $\Delta H =$ 180.7 kJ
- $2NO(g) + O_2(g)$ ----> $2NO_2(g)$ $\Delta H =$ -113.1 kJ
- $2N_2O(g)$ ----> $2N_2(g) + O_2(g)$ $\Delta H =$ -163.2 kJ
- use Hess' s law to calculate ΔH for the reaction:
- $N_2O(g) + NO_2(g)$ ----> $3NO(g)$

Hess’ s law, example:

- Given:
- $N_2(g) + O_2(g)$ ----> $2NO(g)$ ΔH = 180.7 kJ
- $2NO(g) + O_2(g)$ ----> $2NO_2(g)$ ΔH = -113.1 kJ
- $2N_2O(g)$ ----> $2N_2(g)$ + $O_2(g)$ ΔH = -163.2 kJ
- use Hess’ s law to calculate ΔH for the reaction:
- $N_2O(g) + NO_2(g)$ ----> $3NO(g)$

- $N_2O(g)$ ----> $\cancel{N_2(g)}$ + $\cancel{1/2O_2}(g)$ ΔH = -163.2/2 =-81.6kJ
- $NO_2(g)$ ----> $NO(g)$ + $\cancel{1/2O_2(g)}$ ΔH = 113.1 kJ/2=56.6kJ
- $\cancel{N_2(g)}$ + $\cancel{O_2(g)}$ ----> $2NO(g)$ ΔH = 180.7

- $N_2O(g) + NO_2(g)$ ----> $3NO(g)$ ΔH = 155.7 kJ

Enthalpies of Formation

An enthalpy of formation, ΔH_f, is defined as the ΔH for the reaction in which a compound is made from its constituent elements in their ***most stable*** elemental forms.

- $2Al + Fe_2O_3$ -------> $Al_2O_3 + 2Fe$

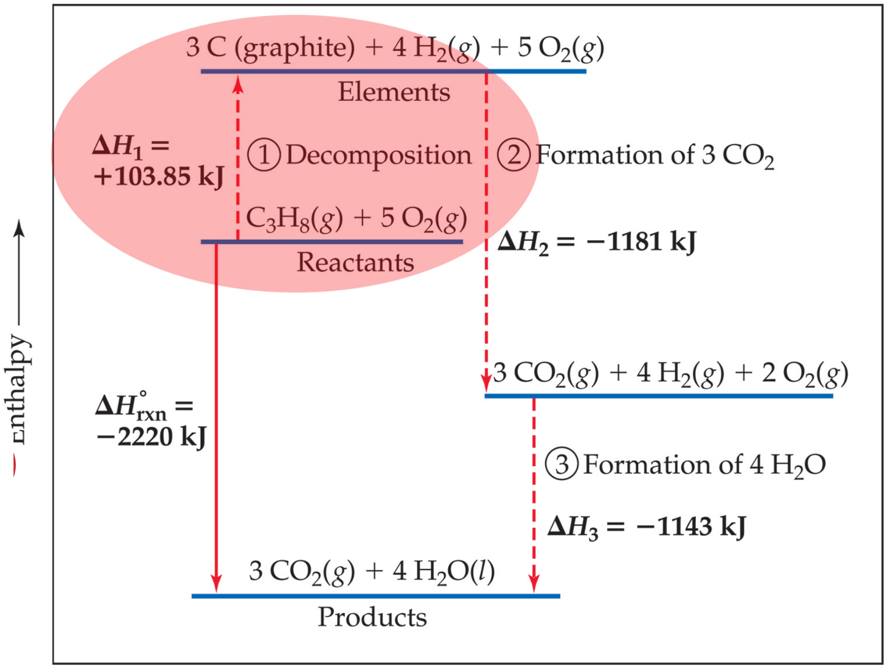
- What is the heat of reaction given:
- $2Fe + 3/2O_2$ -----> Fe_2O_3 ΔH = -825.5 KJ (heat of formation)
- $2Al + 3/2O_2$ -----> Al_2O_3 ΔH = -1675.7 KJ (heat of formation)

Calculation of ΔH

$$C_3H_8\,(g) + 5\,O_2\,(g) \longrightarrow 3\,CO_2\,(g) + 4\,H_2O\,(l)$$

- Imagine this as occurring in 3 steps:

$$C_3H_8\,(g) \longrightarrow 3\,C_{(\text{graphite})} + 4\,H_2\,(g)$$



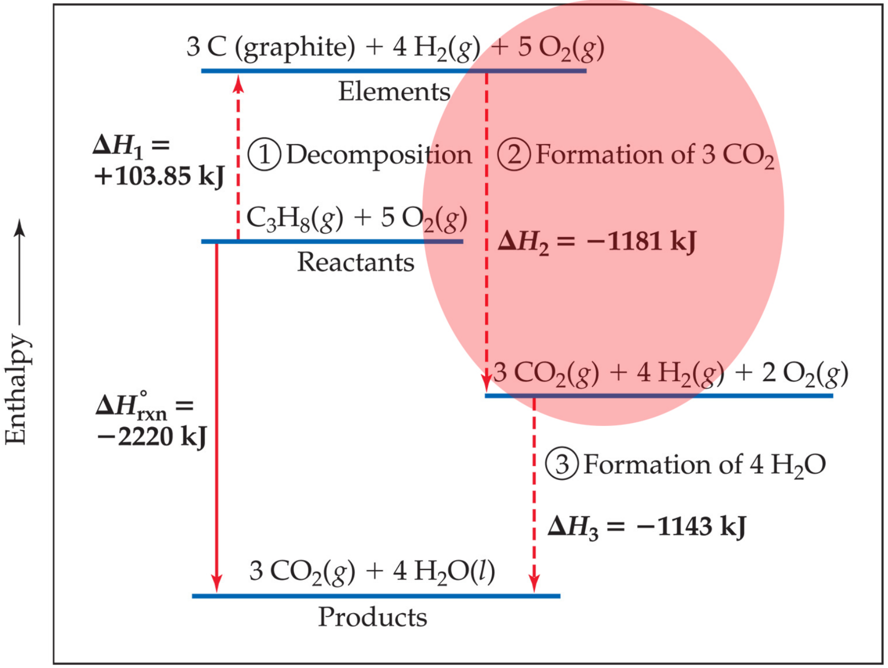
Calculation of Δ*H*

$$C_3H_8\,(g) + 5\,O_2\,(g) \longrightarrow 3\,CO_2\,(g) + 4\,H_2O\,(l)$$

- Imagine this as occurring in 3 steps:

$$C_3H_8\,(g) \longrightarrow 3\,C_{(graphite)} + 4\,H_2\,(g)$$

$$3\,C_{(graphite)} + 3\,O_2\,(g) \longrightarrow 3\,CO_2\,(g)$$



Calculation of Δ*H*

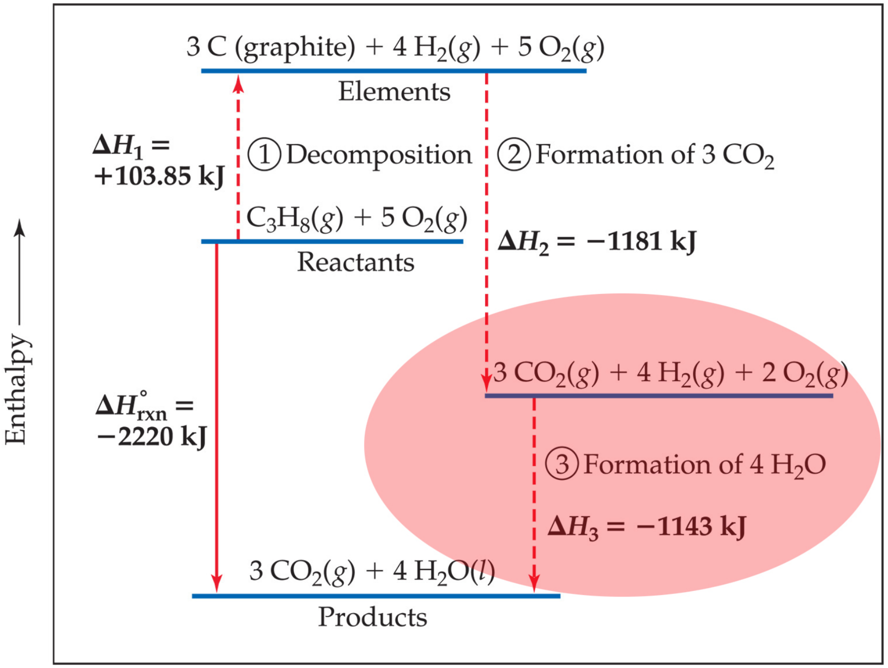
$$C_3H_8\,(g) + 5\,O_2\,(g) \longrightarrow 3\,CO_2\,(g) + 4\,H_2O\,(l)$$

- Imagine this as occurring in 3 steps:

$$C_3H_8\,(g) \longrightarrow 3\,C_{(graphite)} + 4\,H_2\,(g)$$

$$3\,C_{(graphite)} + 3\,O_2\,(g) \longrightarrow 3\,CO_2\,(g)$$

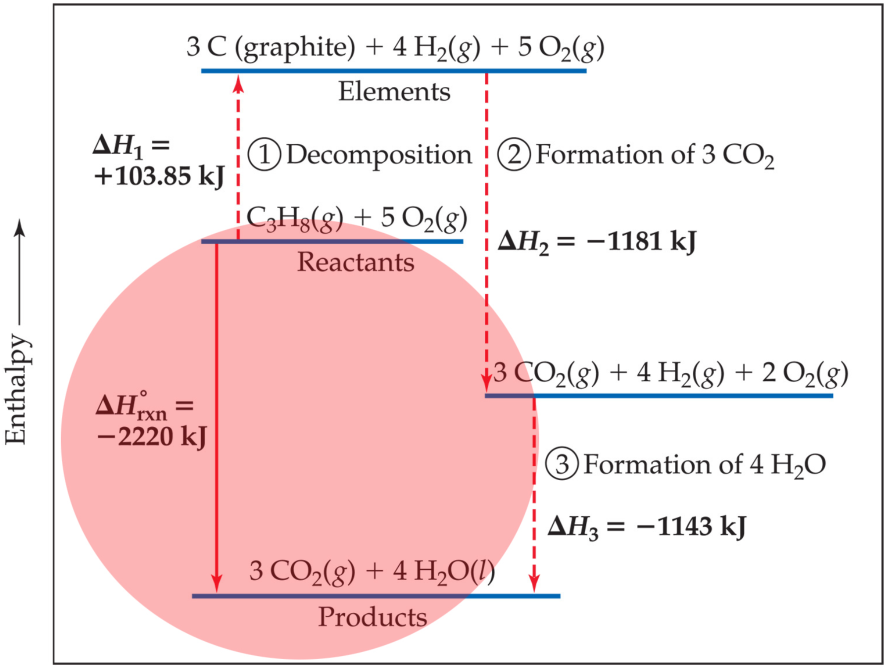
$$4\,H_2\,(g) + 2\,O_2\,(g) \longrightarrow 4\,H_2O\,(l)$$



Calculation of Δ*H*

$$C_3H_8\,(g) + 5\,O_2\,(g) \longrightarrow 3\,CO_2\,(g) + 4\,H_2O\,(l)$$

- The sum of these equations is:



$$C_3H_8\,(g) \longrightarrow \cancel{3\,C}_{(graphite)} + \cancel{4\,H_2}\,(g)$$

$$\cancel{3\,C}_{(graphite)} + 3\,O_2\,(g) \longrightarrow 3\,CO_2\,(g)$$

$$\cancel{4\,H_2}\,(g) + 2\,O_2\,(g) \longrightarrow 4\,H_2O\,(l)$$

$$C_3H_8\,(g) + 5\,O_2\,(g) \longrightarrow 3\,CO_2\,(g) + 4\,H_2O\,(l)$$

Make each reactant or product from its elements
This is called the heat of formation of a compound

Calculation of ΔH

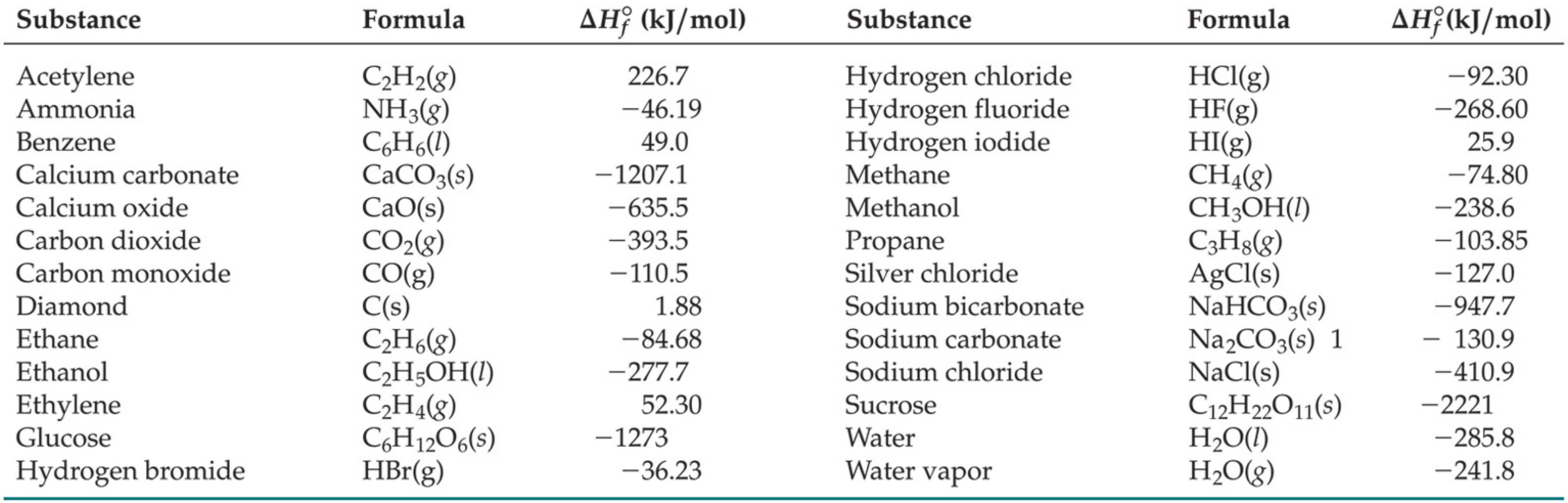
We can use Hess' s law in this way:

$$\Delta H = \Sigma\, n\, \Delta H^{\circ}_{f\text{(products)}} - \Sigma\, m\, \Delta H^{\circ}_{f\text{(reactants)}}$$

where n and m are the stoichiometric coefficients.

Standard Enthalpies of Formation

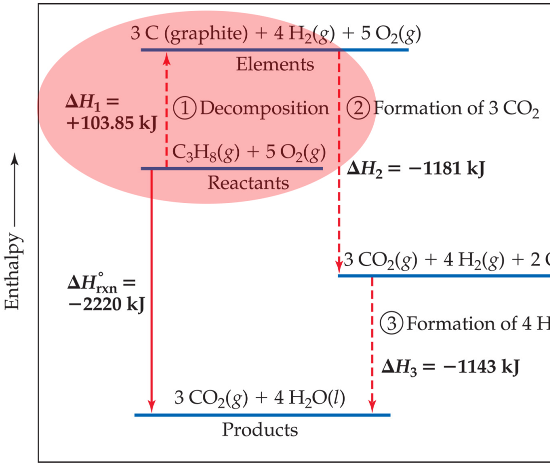
Standard enthalpies of formation, ΔH_f°, are measured under standard conditions (25°C and 1.00 atm pressure).

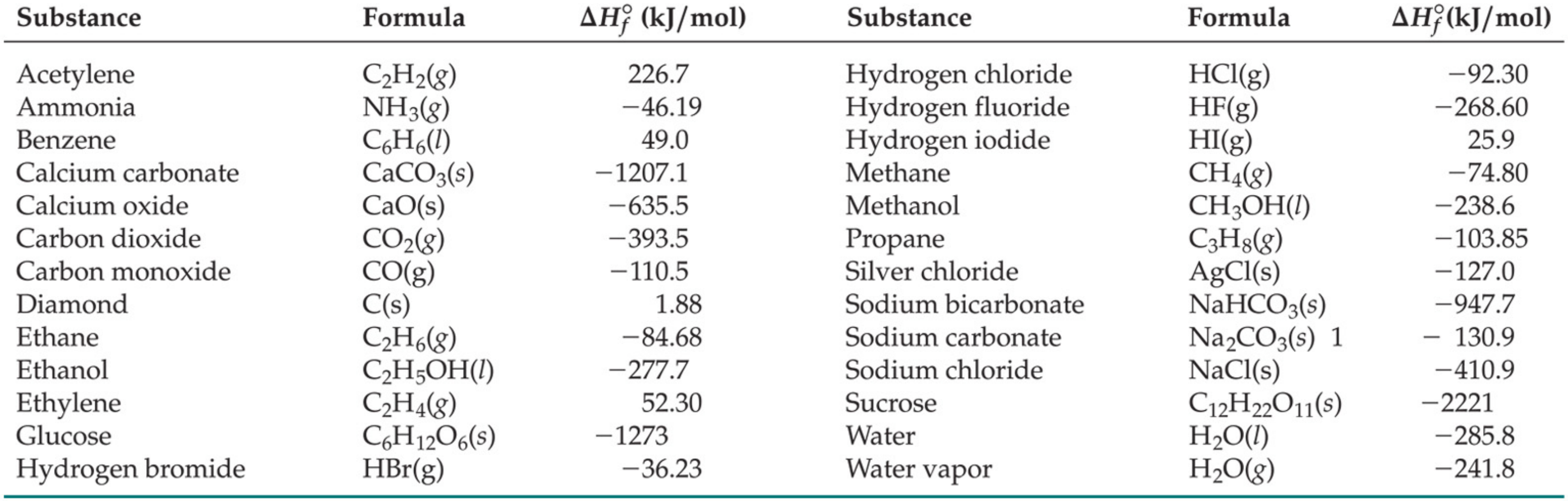


Substance	**Formula**	**ΔH_f° (kJ/mol)**	**Substance**	**Formula**	**ΔH_f° (kJ/mol)**
Acetylene	$C_2H_2(g)$	226.7	Hydrogen chloride	$HCl(g)$	−92.30
Ammonia	$NH_3(g)$	−46.19	Hydrogen fluoride	$HF(g)$	−268.60
Benzene	$C_6H_6(l)$	49.0	Hydrogen iodide	$HI(g)$	25.9
Calcium carbonate	$CaCO_3(s)$	−1207.1	Methane	$CH_4(g)$	−74.80
Calcium oxide	$CaO(s)$	−635.5	Methanol	$CH_3OH(l)$	−238.6
Carbon dioxide	$CO_2(g)$	−393.5	Propane	$C_3H_8(g)$	−103.85
Carbon monoxide	$CO(g)$	−110.5	Silver chloride	$AgCl(s)$	−127.0
Diamond	$C(s)$	1.88	Sodium bicarbonate	$NaHCO_3(s)$	−947.7
Ethane	$C_2H_6(g)$	−84.68	Sodium carbonate	$Na_2CO_3(s)$ 1	− 130.9
Ethanol	$C_2H_5OH(l)$	−277.7	Sodium chloride	$NaCl(s)$	−410.9
Ethylene	$C_2H_4(g)$	52.30	Sucrose	$C_{12}H_{22}O_{11}(s)$	−2221
Glucose	$C_6H_{12}O_6(s)$	−1273	Water	$H_2O(l)$	−285.8
Hydrogen bromide	$HBr(g)$	−36.23	Water vapor	$H_2O(g)$	−241.8

Calculation of ΔH

- Calculate ΔH using the table:
- $C_3H_{8(g)}$ + 5 $O_{2(g)}$ -----> $3CO_{2(g)}$ + $4H_2O(l)$





Substance	Formula	ΔH°_f (kJ/mol)	Substance	Formula	ΔH°_f (kJ/mol)
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Hydrogen bromide	$HBr(g)$	−36.23	Water vapor	$H_2O(g)$	−241.8

Calculation of ΔH

- C_3H_8 + 5 O_2 -----> 3CO_2 + 4H_2O

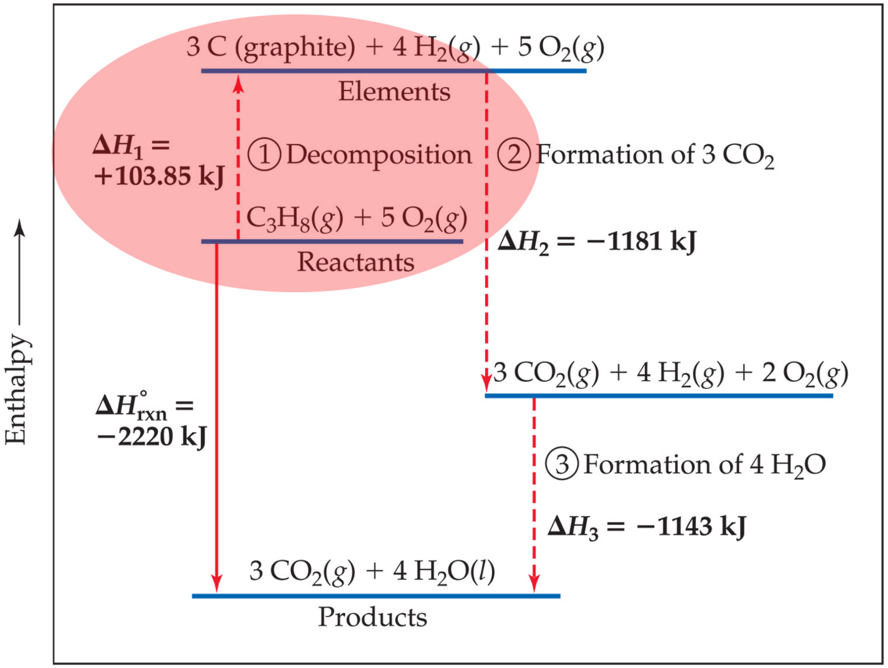
$\Delta H = [3(\Delta H_f CO_2) + 4(\Delta H_f H_2O)] - [(\Delta H_f C_3H_8) + (5\Delta H_f O_2)]$

$= [3(-393.5\ kJ) + 4(-285.8\ kJ)] - [(-103.85\ kJ) + 5(0)$

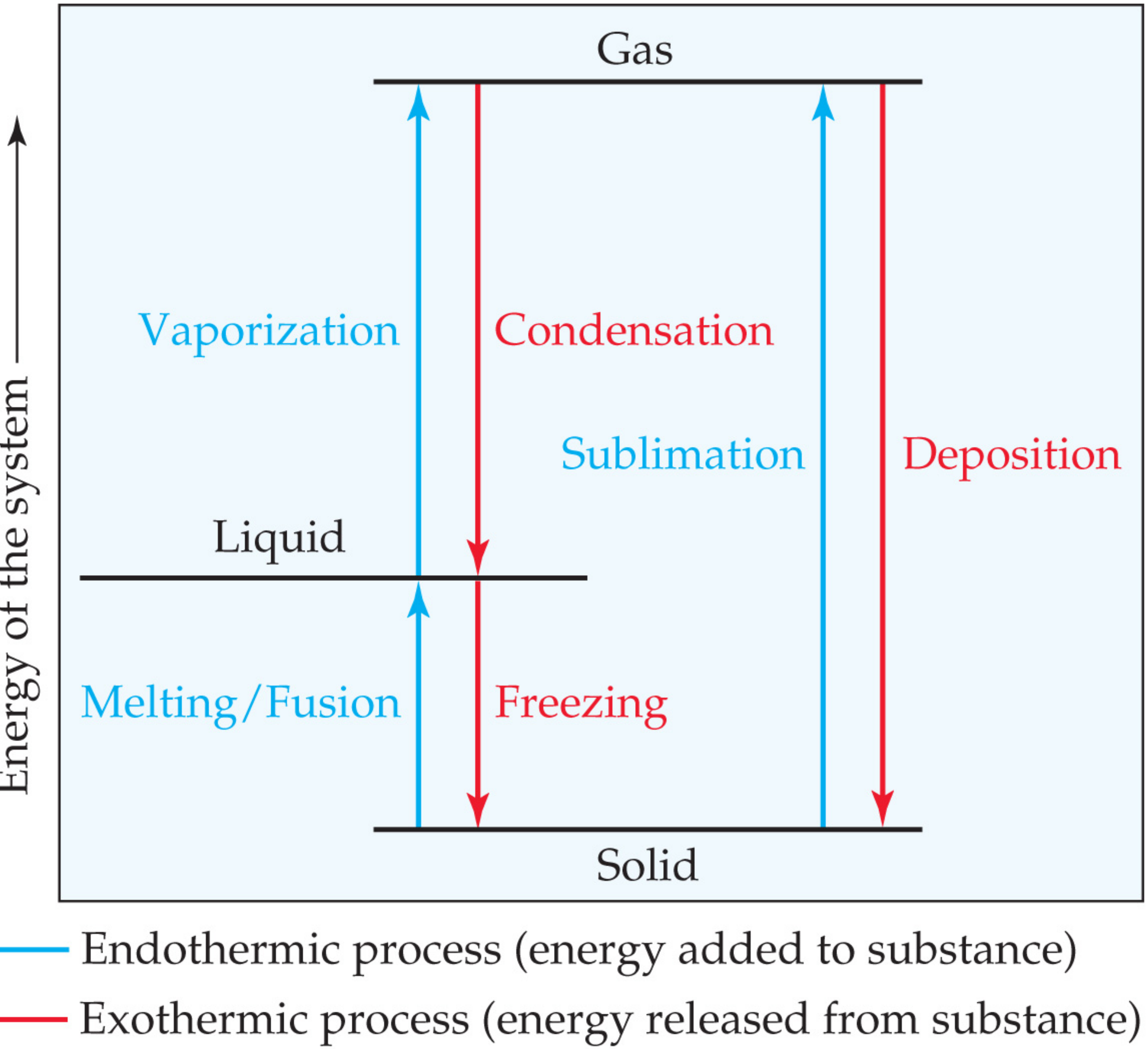
$= [-1180.5\ kJ + (-1143.2\ kJ)] - [(-103.85\ kJ) + 0\ kJ$

$= [-2323.7\ kJ] - [-103.85\ kJ)$

$= -2219.9\ kJ$



Phase Changes

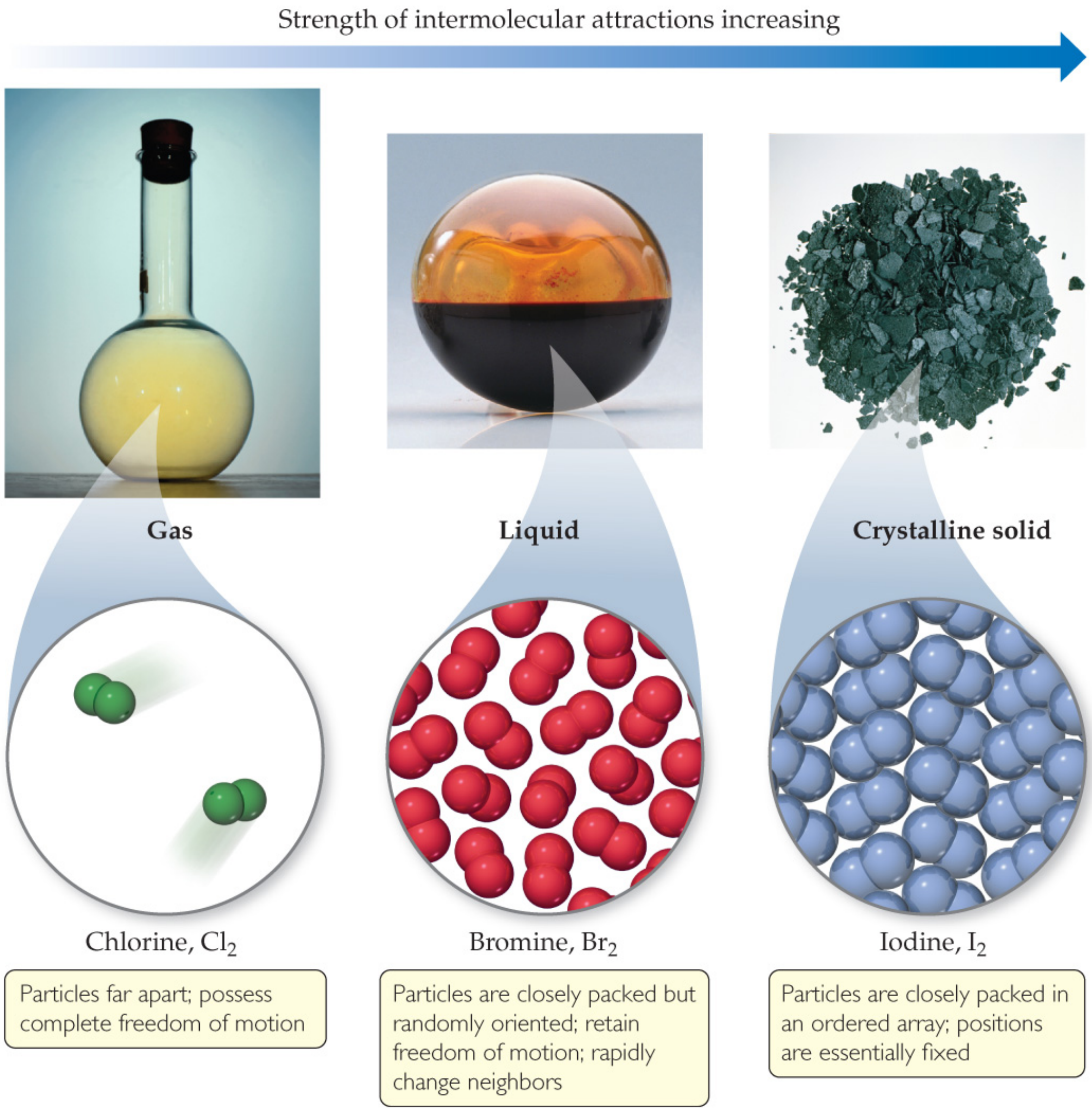


- Conversion from one state of matter to another is a **phase change**.

Energy is either added or released in a phase change.

.

Why is E (Q,H) transferred in phase change?



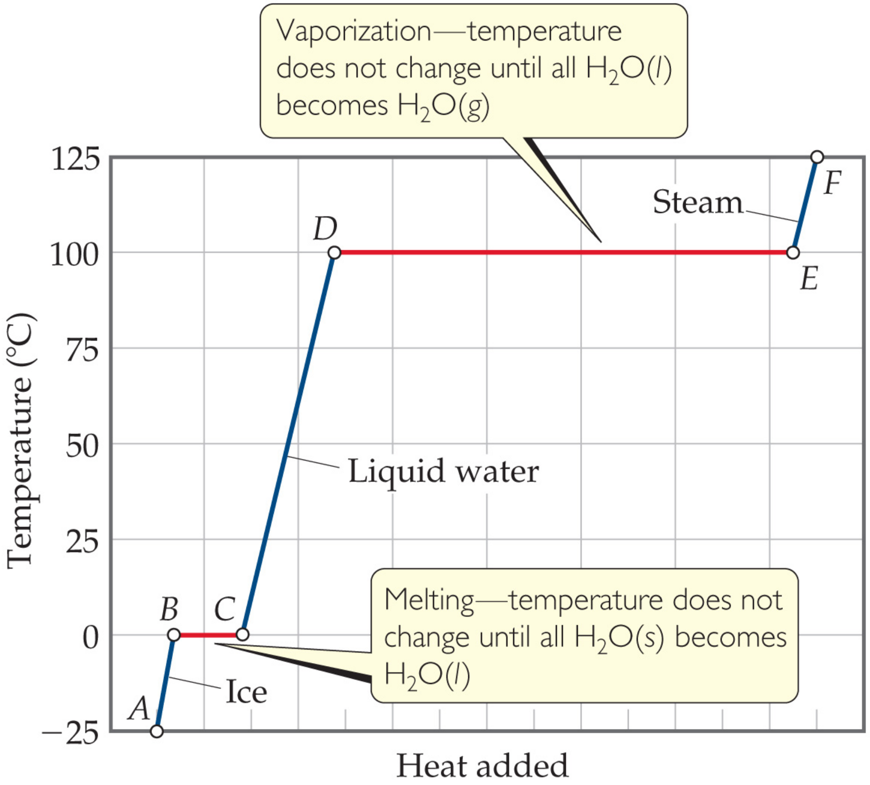
Particles far apart; possess complete freedom of motion

Particles are closely packed but randomly oriented; retain freedom of motion; rapidly change neighbors

Particles are closely packed in an ordered array; positions are essentially fixed

- Atoms/molecules stick to each other in liquid/ solid, always stick more in solid.
- Atoms/molecules don't touch in gas.
- Liquid to gas, E is needed to pull the atoms/molecules from each other.

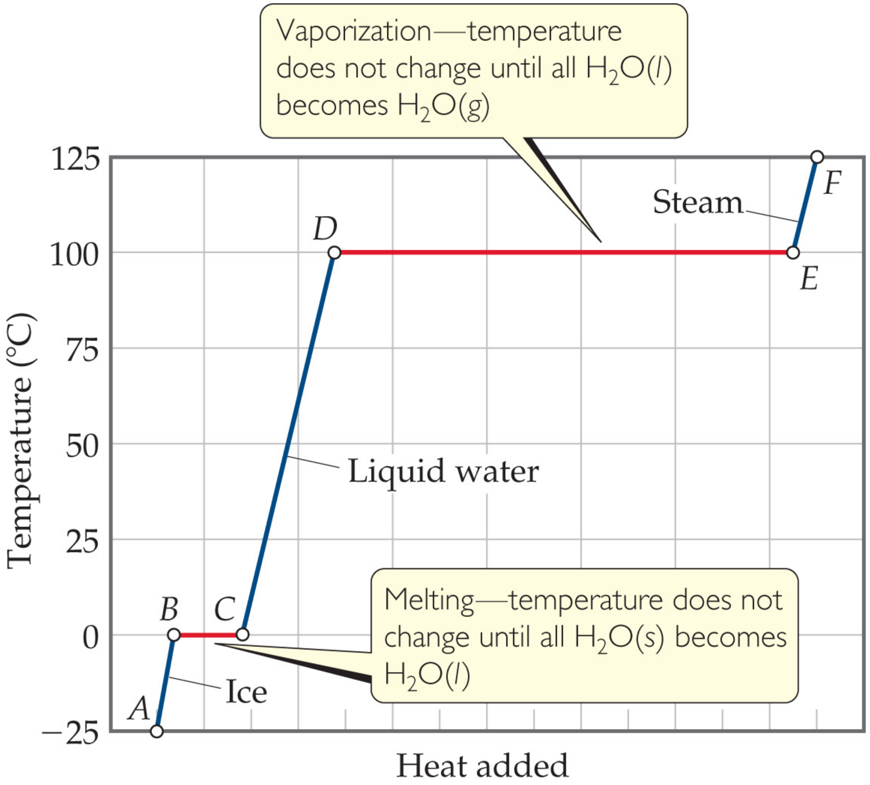
Heating Curves



- A plot of T vs. q
- Within a phase:
- q= ms
- The temperature of the substance does not rise during a phase change.

- For the phase changes, the product of mass and the heat of fusion of vaporization is heat.

Heating Curves



- A plot of T vs. q
- Within a phase:
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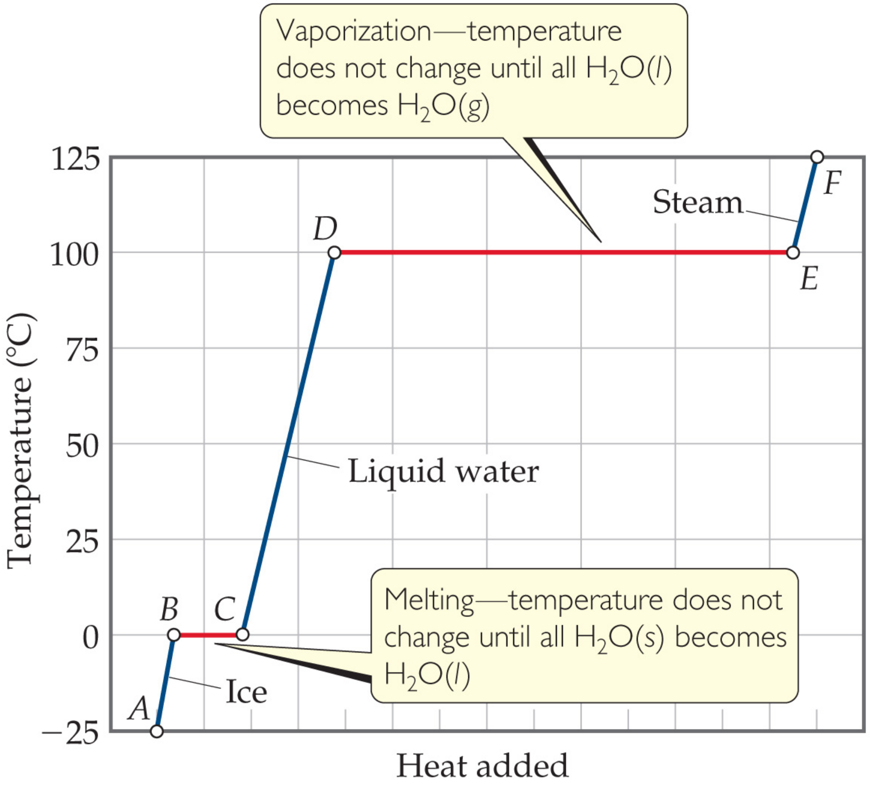
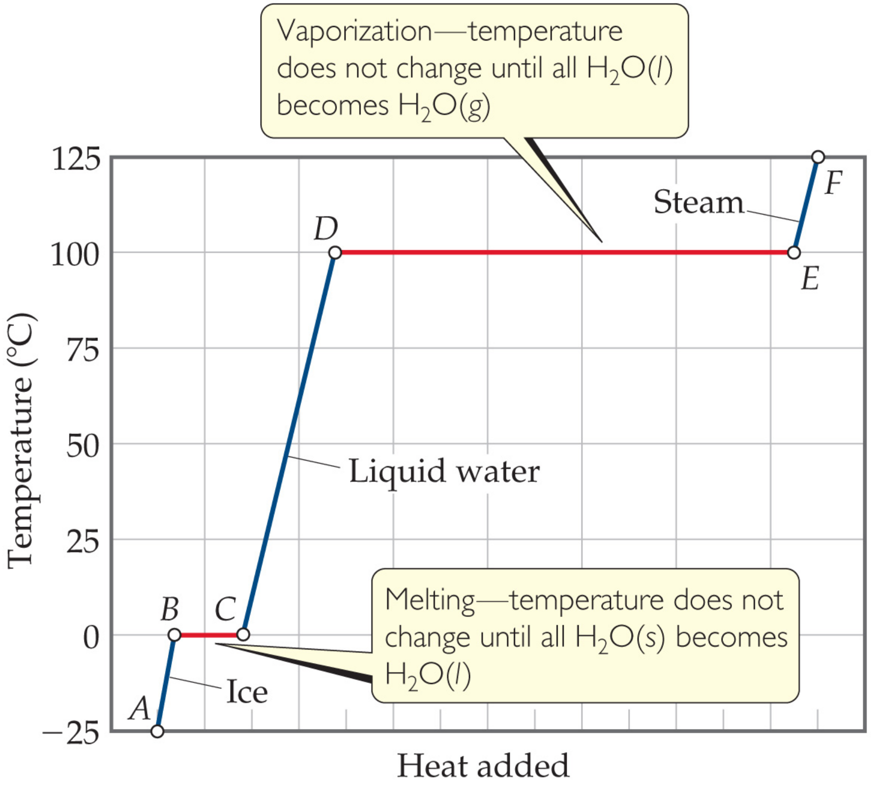
Heating Curves



- A plot of T vs. q
- Within a phase:
- q= $ms\Delta T$
- During melting:
- $q=\Delta H_{Fus}m$
- During boiling:
- $q= \Delta H_{vap}m$

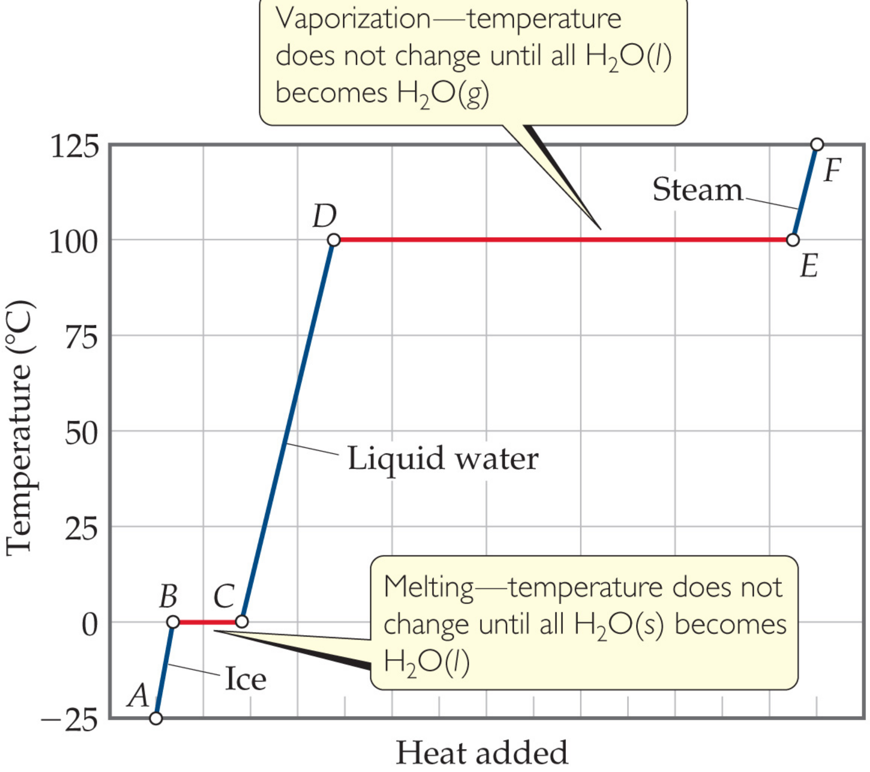
- For the phase changes, the product of mass and the heat of fusion of vaporization is heat.

Example:



- Calculate q for taking 10g ice from A to F:

- For the phase changes, the product of mass and the heat of fusion of vaporization is heat.



Example:

ΔH_{Fus} water: 334 J/g

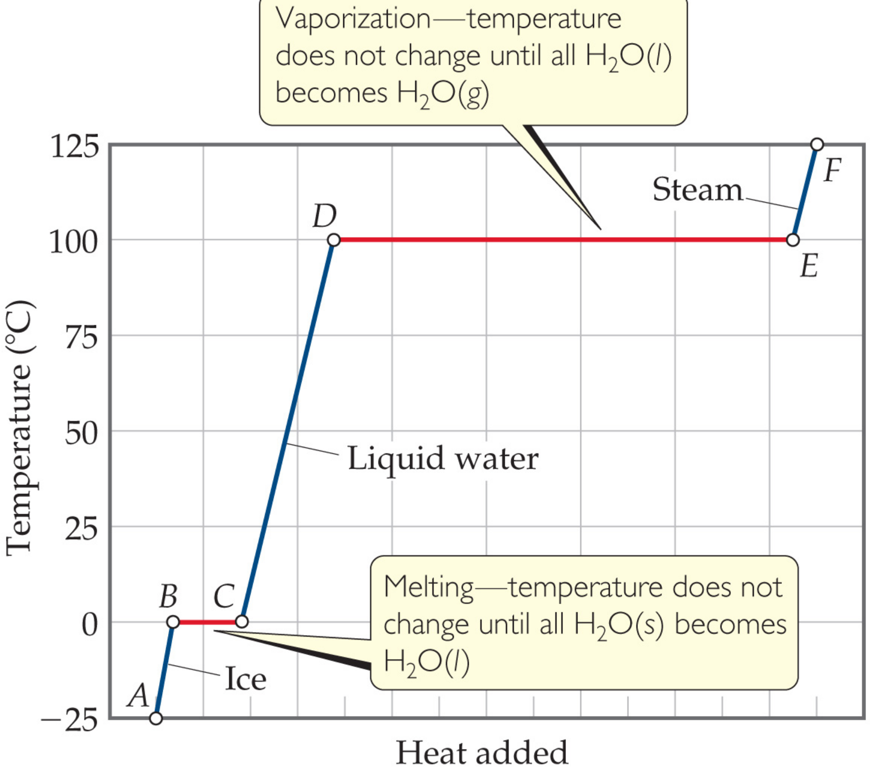
Δh_{vap} water: 2444 J/g

s water: 4.184 J/g°K

s ice: 2.05 J/gK

s vapor: 2.00 J/gK

Example:



Vaporization—temperature does not change until all $H_2O(l)$ becomes $H_2O(g)$

Melting—temperature does not change until all $H_2O(s)$ becomes $H_2O(l)$

ΔH_{Fus} water: 334 J/g
Δh_{vap} water: 2444 J/g
s water: 4.184 J/g°K
s ice: 2.05 J/gK
s vapor: 2.00 J/gK

- Calculate q for taking 10g ice from A to F:
- A-> B: (10g)2.05J/gK(25°C) = 512.5 J
- B-> C: 10g(334 J/g) =3340 J
- C -> D: 10g(4.184 J/gK)(100 K) = 4184 J
- D -> E: 10g(2444 J/g) = 24440 J
- E -> F: 10g(2.00 J/gK)(25 K) = 500 J
- TOTAL = 32977 J

Energy in Foods

Most of the fuel in the food we eat comes from carbohydrates and fats.

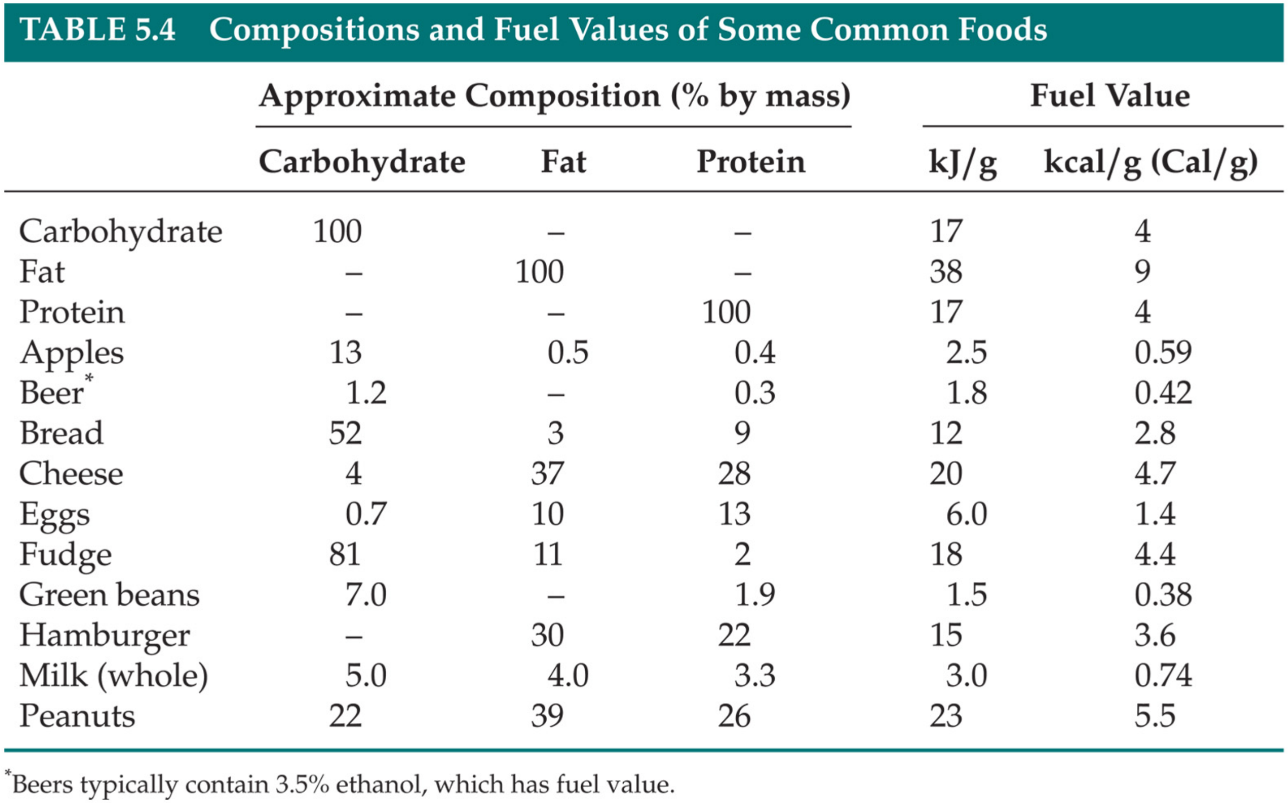


TABLE 5.4 Compositions and Fuel Values of Some Common Foods

	Approximate Composition (% by mass)			Fuel Value	
	Carbohydrate	Fat	Protein	kJ/g	kcal/g (Cal/g)
Carbohydrate	100	–	–	17	4
Fat	–	100	–	38	9
Protein	–	–	100	17	4
Apples	13	0.5	0.4	2.5	0.59
Beer*	1.2	–	0.3	1.8	0.42
Bread	52	3	9	12	2.8
Cheese	4	37	28	20	4.7
Eggs	0.7	10	13	6.0	1.4
Fudge	81	11	2	18	4.4
Green beans	7.0	–	1.9	1.5	0.38
Hamburger	–	30	22	15	3.6
Milk (whole)	5.0	4.0	3.3	3.0	0.74
Peanuts	22	39	26	23	5.5

*Beers typically contain 3.5% ethanol, which has fuel value.

What’s the deal with fat?

- Carbohydrates:
- $C_nH_{2n}O_n$ +nO_2 --> --> --> nCO_2 + nH_2O + Energy

- Fats:

more steps

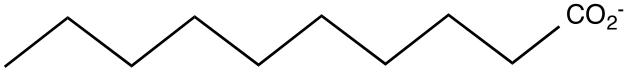
- $C_nH_{2n}O_2$ + mO_2--> --> --> --> --> --> nCO_2 + nH_2O

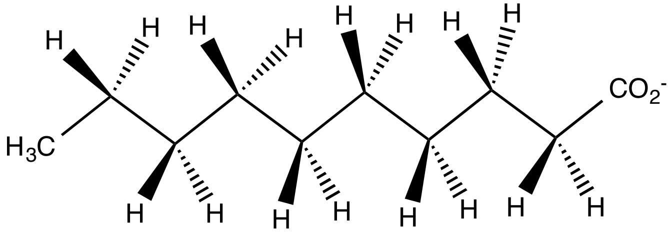
Fat storage.

It also clogs your arteries.

Energy and oxidation states

- Oxidation state of C in a fatty acid:



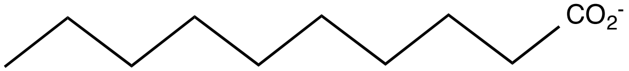


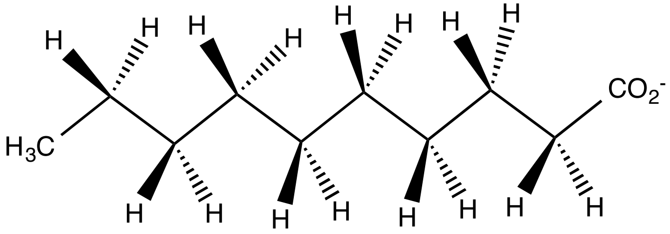
- Oxidation state of C in glucose:

- $C_6H_8O_6$

Energy and oxidation states

- Oxidation state of C in a fatty acid:



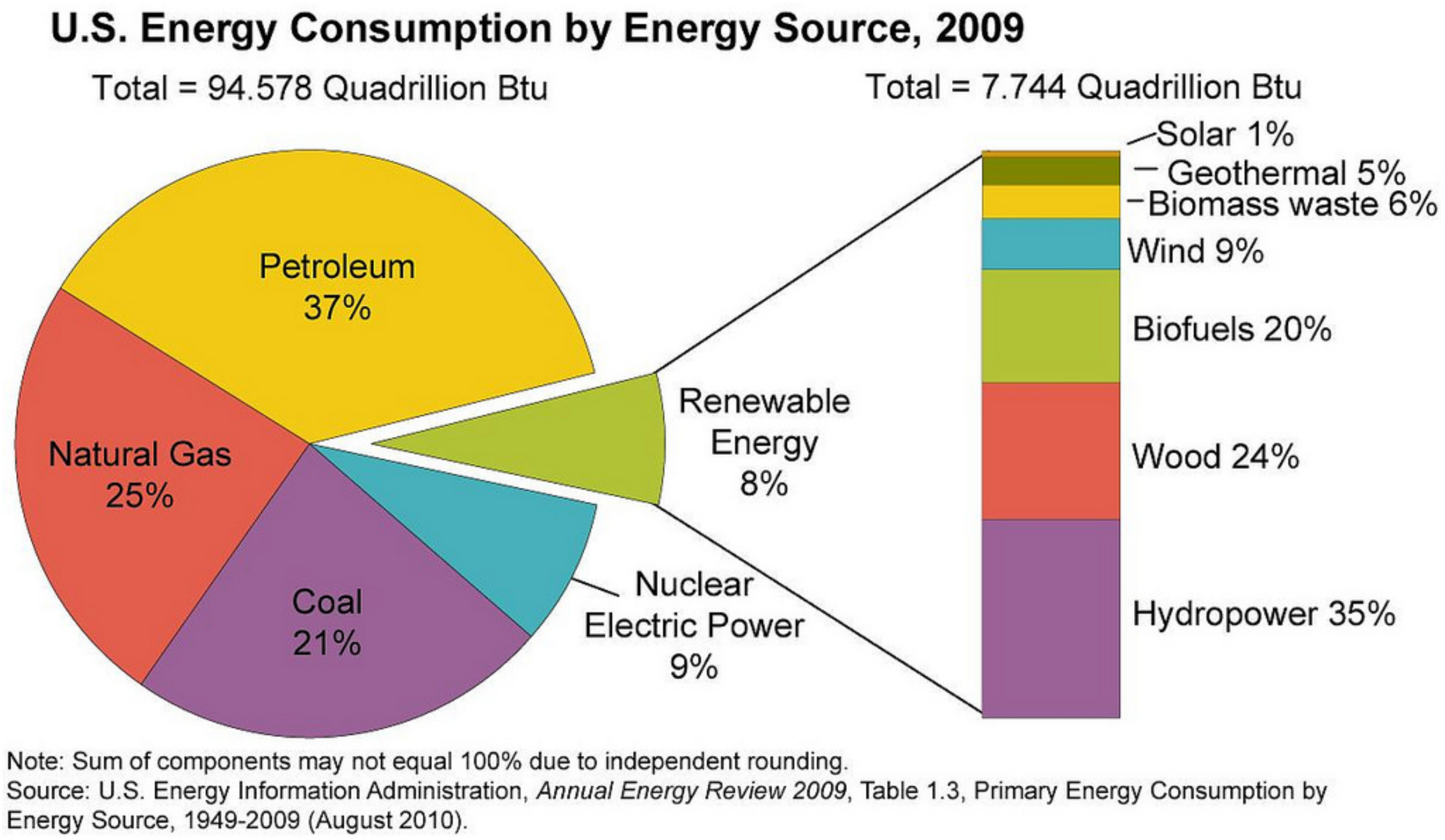


-3 -2 -2 -2 -2 -2 -2 -2 +3

- Oxidation state of C in glucose:
- $C_6H_{12}O_6$
- 0
- Both go to CO_2 C: +4

Fuels

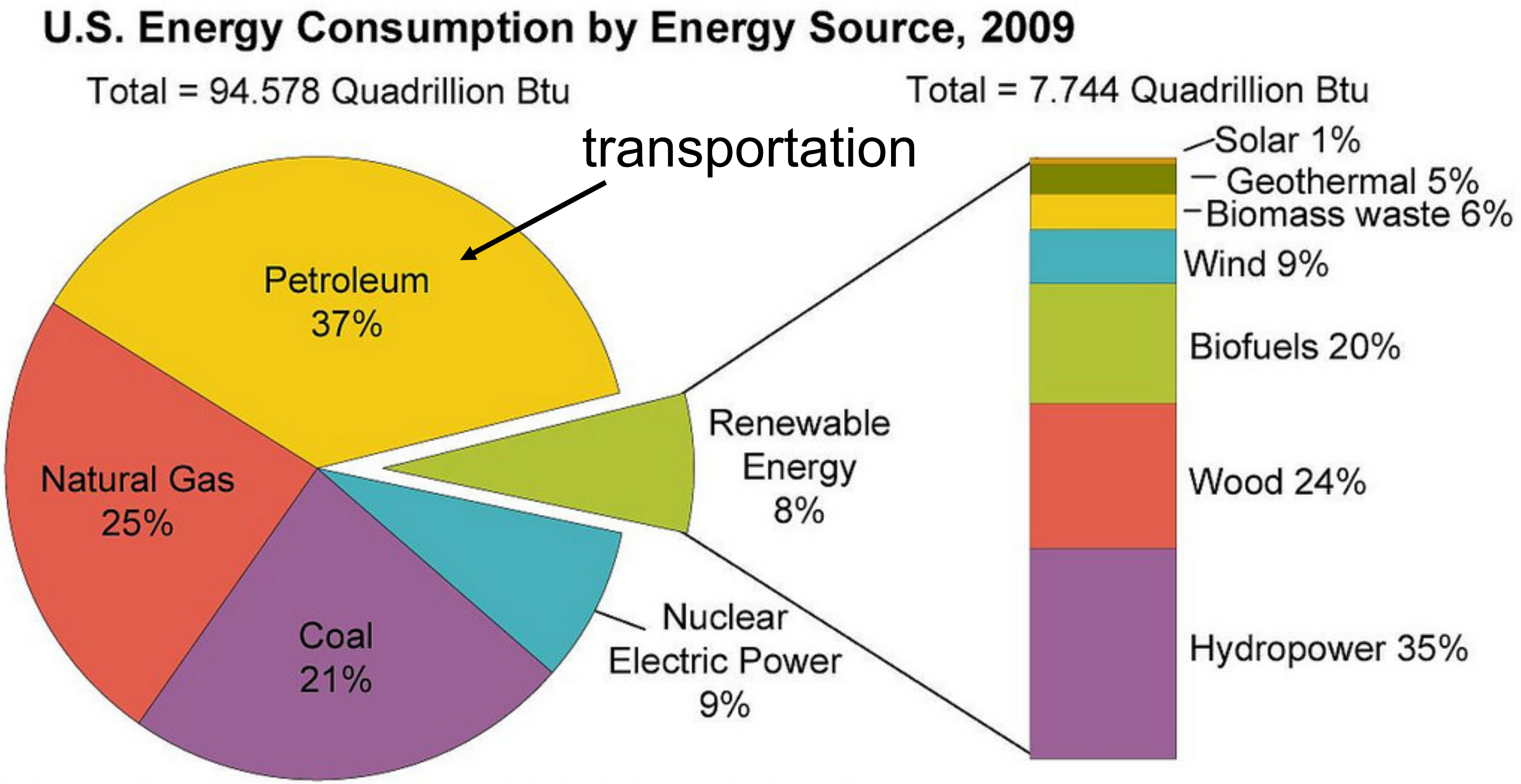
The vast majority of the energy consumed in this country comes from fossil fuels.



Note: Sum of components may not equal 100% due to independent rounding.
Source: U.S. Energy Information Administration, *Annual Energy Review 2009*, Table 1.3, Primary Energy Consumption by Energy Source, 1949-2009 (August 2010).

Major issues

- Portable fuel (liquid, relatively light), transportation
- Non-portable fuel (makes electricity).



U.S. Energy Consumption by Energy Source, 2009

Note: Sum of components may not equal 100% due to independent rounding.
Source: U.S. Energy Information Administration, *Annual Energy Review 2009*, Table 1.3, Primary Energy Consumption by Energy Source, 1949-2009 (August 2010).

The Energy cycle:

- Us (and almost everything else alive on the earth):
- $C_6H_{12}O_6 + 6O_2 \dashrightarrow 6CO_2 + 6H_2O$

- Fossil fuel production:
- $CH_4 + 2O_2 \dashrightarrow CO_2 + 2H_2O$ (for methane)

- Plants:
- $6CO_2 + 6H_2O + \text{light} \dashrightarrow C_6H_{12}O_6 + 6O_2$

Net CO_2 production could therefore be 0.

Energy research on Campus

ADREC

Anaerobic digestor

Energy research on Campus
ADREC
Anaerobic digestor

- Anaerobic Digestion:
- $C_6H_{12}O_6 \xrightarrow{\text{bacteria}} 3CO_2 + 3CH_4$

Basically:

Poop $\rightarrow$ $CO_2 + CH_4$

https://www.egr.msu.edu/bae/adrec/feature/south-campus-anaerobic-digester

Hydrogen, the perfect fuel?

$2H_2 + O_2$ -----> $2H_2O$ $\Delta H = -285$ kJ/mol H_2(1mol/2g)= -142 kJ/g

This is literally what fuel cells do. You get nothing but water!

The problem with oil

- Not “renewable” (will run out)
- Pollution (combustion not perfect).
- Global warming

CO_2 absorbs heat.

C_nH_{2n+2} + (3n+1/2)O_2 -----> nCO_2 + (n+1)H_2O

Efficiency/conservation

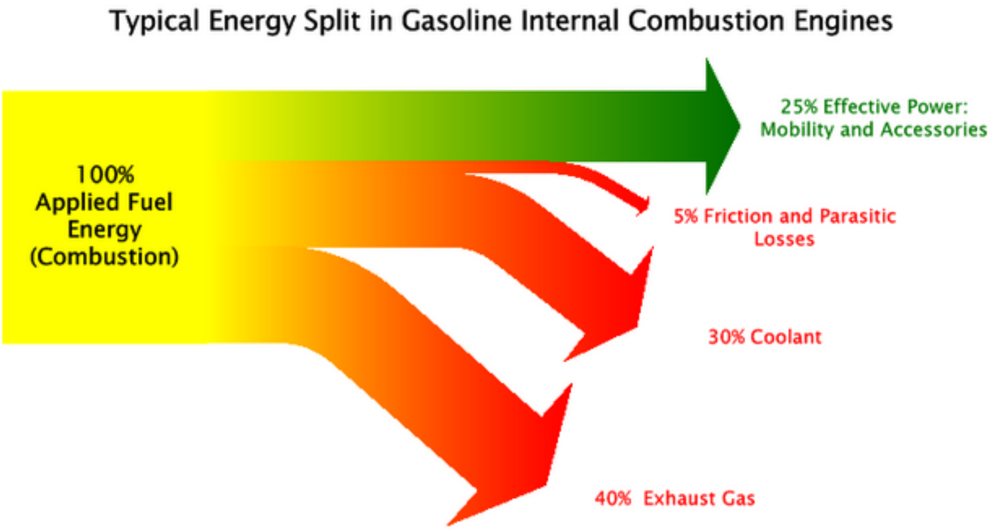
- U.S. could decrease energy needs by 20-50% by being less wasteful.
- High mileage cars
- more energy efficient building/homes.

Hybrid car

- Gas engine plus electric motor
- Why?
- All the energy is still coming from burning gasoline.

Hybrids

- Electric motors are way more efficient than gas engines. (94%)
- Note, your engine is very hot,
- It must be cooled
- Flush all that E down drain. No work, only heat.



gas engines are 24-30% efficient

Problem: batteries suck!
Heavy, expensive, limited recharging cycles, limited current etc.

Li ion battery

$x\,e^- + xLi^+ + Li_{1-x}Co(IV)O_2 \text{ -----> } LiCo(III)O_2$

$Li_xC_6 \text{ ------> } xLi^+ + xe^- + C_6$

Lithium is really light.
Dissolves in organic solvents which are also light.
Li is at the top of the activity series. Means a higher potential (more voltage per battery cell)

Hybrids

- Electric motors work at low speeds
- gas engine shuts off when not needed
- at low speeds, stop lights, etc.
- (infinite torque, really go from 0-15)
- Gas engine charges battery and is used at higher speeds
- Hybrids get BETTER gas milage in town versus highway

Other sources
How much bang for your buck?

	Approximate Elemental Composition (mass %)			
	C	H	O	Fuel Value (kJ/g)
Wood (pine)	50	6	44	18
Anthracite coal (Pennsylvania)	82	1	2	31
Bituminous coal (Pennsylvania)	77	5	7	32
Charcoal	100	0	0	34
Crude oil (Texas)	85	12	0	45
Gasoline	85	15	0	48
Natural gas	70	23	0	49
Hydrogen	0	100	0	142

The problem with Hydrogen

Storage

gas, less dense, hard to get enough in the car and have trunk space

Kaboom (Hindenburg)

Where do you get the hydrogen?

The problem with Hydrogen

Where do you get the hydrogen? (*petroleum*)

$CH_4(g) + H_2O(g)$ ---→ $CO(g) + H_2(g)$

$CO(g) + H_2O(g)$ -→ $CO_2(g) + H_2(g)$

Mahler IGS, 200

Ethanol, where does it come from

- Alcoholic fermentation:
- $C_6H_{12}O_6$ ----> $2CO_2$ + $2C_2H_5OH$ (ethanol) ΔH=-76 kJ/mol
- -1270 2(-393) 2(-280)
- (anaerobic, bacteria & yeast can do this, we can't)

Exactly the same place it comes from in your beer.

Ethanol

- Alcoholic fermentation:
- $C_6H_{12}O_6 \xrightarrow{\text{bug}} 2CO_2 + 2C_2H_6O$ (ethanol) $\Delta H = -76$ kJ/mol
- -1270 2(-393) 2(-280)
- (anaerobic, yeast can do this, we can’t) only to 10%.
- Distillation (requires energy) to purify.

Alcohol combustion:

$C_2H_6O + O_2 \longrightarrow 2CO_2 + 3H_2O$ $\Delta H = -1367$ kJ/mol(1mol/46g)=-29.7kJ/g

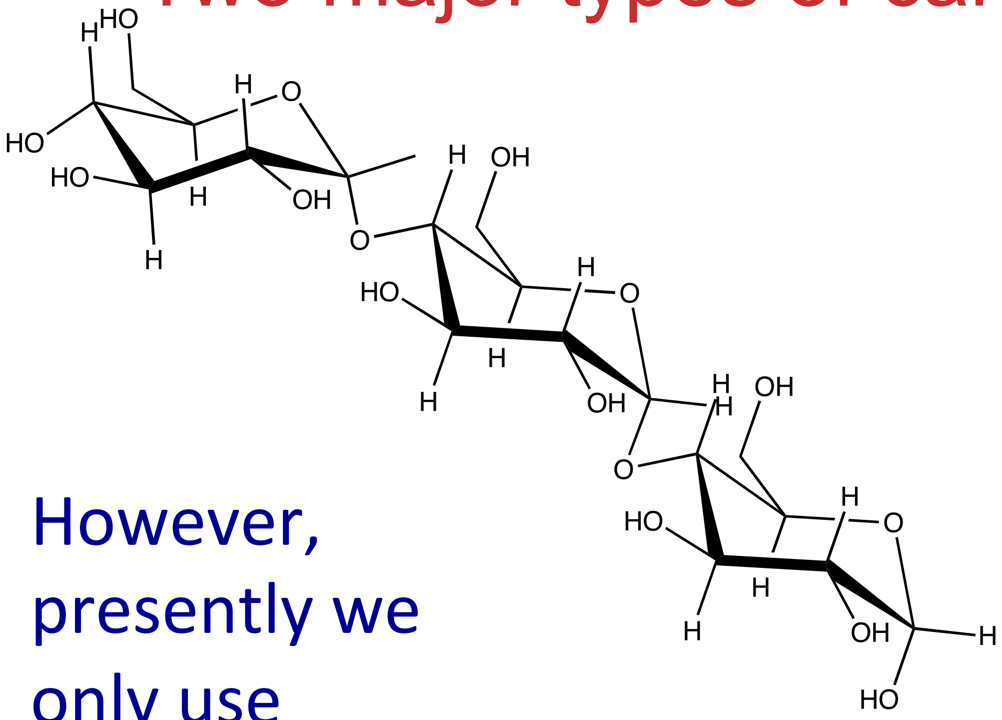
But why would this be better for global warming?

Ethanol, problems

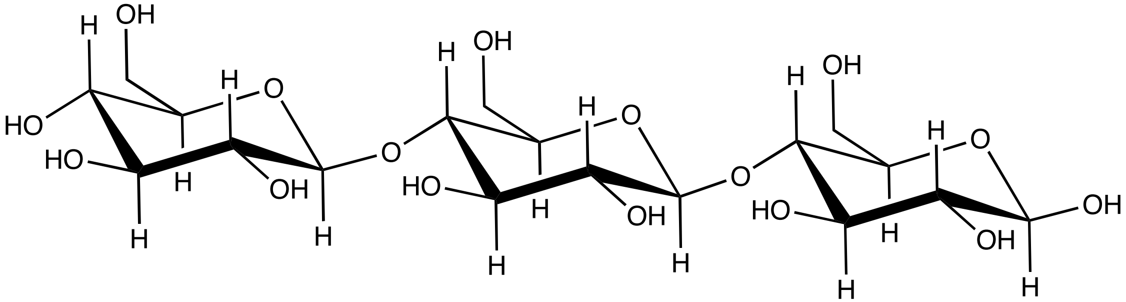
- Lots of land to grow (yield 2-4 tons/acre)
- All present agricultural land in U.S. would not be enough for all transportation needs.
- requires fertilizer, tractors,etc. for growing (energy)
- Distillation requires energy
- For every 1.4 kJ need 1.0 kJ, much more than oil
- Brazil, however, is approaching 50% ethanol for transportation
- Why? Sugar cane, largest starch or sugar yield/acre.
- But, you can’t grow sugar cane on the great plains.

Ethanol

Two major types of carbohydrates in plants



- However, presently we only use Starch,



not cellulose

Most stuff in plants is cellulose

Cellulosic ethanol

- 10+ tons/acre (as opposed to 2-4 tons/acre)
- Can use any crop, not just food crops with high starch ("switch grass").
- Problem: Breaking it down to small sugars that yeast can ferment.
- Need cellulase, the enzyme that breaks this up.
- This is a comparatively easy problem to solve
- (compared to hydrogen.)

Ethanol can work.

Things to consider

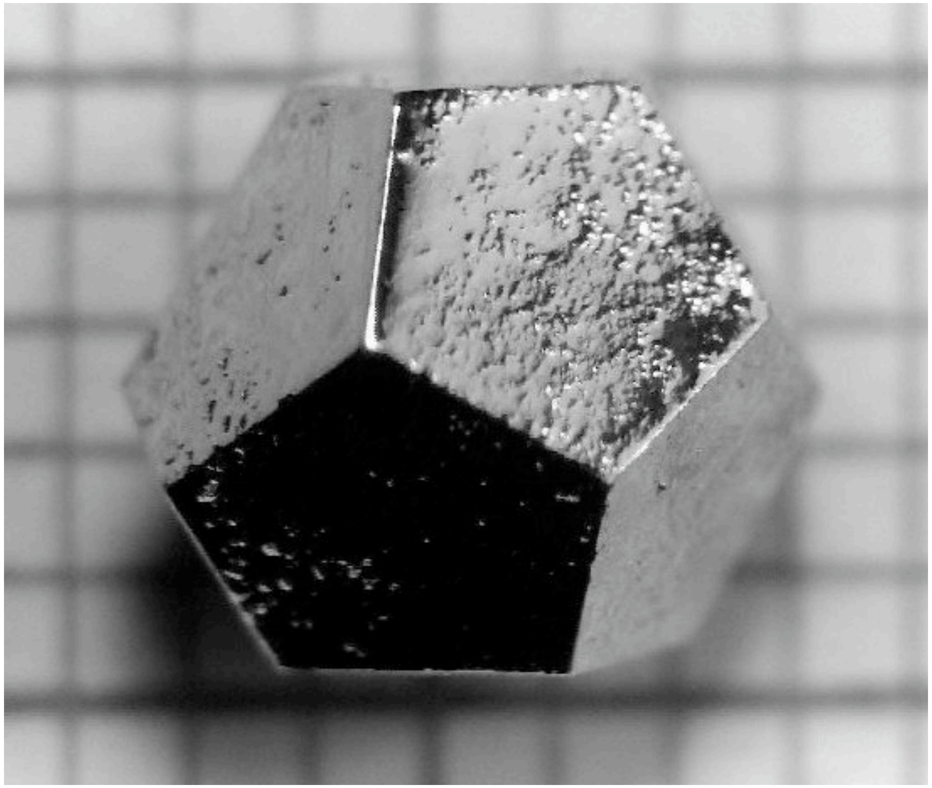
- Energy yield (how much E out versus E in)?
- Break even price (how much/gallon of gas equivalents (present corn ethanol is 2.25/gallon just to make).
- Where is the technology NOW?
- Is storage required, & if so, how you gonna do it
- (solar when the sun doesn't shine)
- Remember, at present Batteries suck!

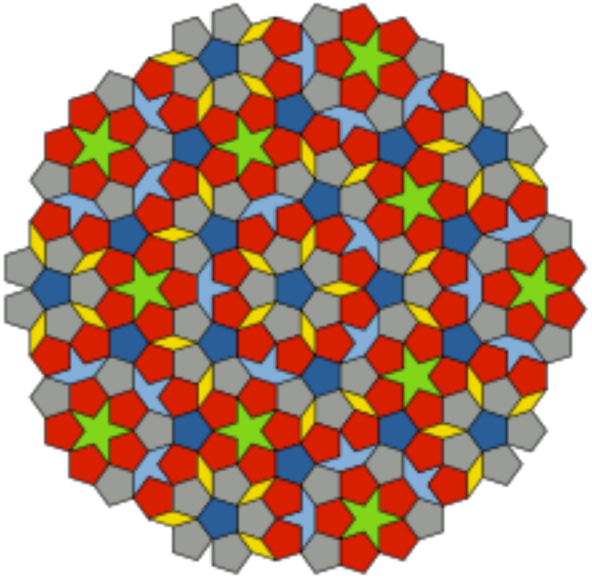
The Chemistry Nobel Prize

- Daniel Shechtman,
- Technion, Israel
- For:
- The discovery of “quasi-crystals” in 1984

The Chemistry Nobel Prize

- An Ho-Mg-Zn quasi-crystal





Note, the five-fold symmetry of the faces!
This was thought to be impossible!
Is this a solid?

The Thermite reaction

- $2Al + Fe_2O_3$ -------> $Al_2O_3 + 2Fe$

- What kind of reaction is this?
- Why does it happen?
- Used for welding railroad tracks
- What is the heat of reaction given:

- $2Fe + 3/2O_2$ -----> Fe_2O_3 $\Delta H = -825.5$ KJ
- $2Al + 3/2O_2$ -----> Al_2O_3 $\Delta H = -1675.7$ KJ

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- $2Al + 3/2O_2$ -----> Al_2O_3 $\Delta H = -1675.7$ KJ
- Fe_2O_3 -----> $2Fe + 3/2O_2$ $\Delta H = 825.5$ KJ

- $2Al + Fe_2O_3$ -------> $Al_2O_3 + 2Fe$ $\Delta H = -850.2$ KJ

A thermite mystery:

http://www.youtube.com/watch?v=BnHR4cMXiyM