

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).

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

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

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

Energy has units of (mass)(velocity)²

Remember kinetic energy was $\frac{1}{2}mv^2$

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:

$$F = ma, \text{ mass}(\text{distance}/\text{s}^2)$$

$$W = F(d) = \text{mass}(\text{distance}^2/\text{s}^2)$$

$$= mv^2$$



(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.

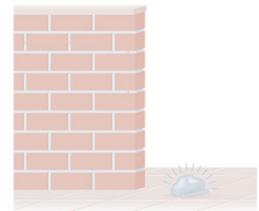
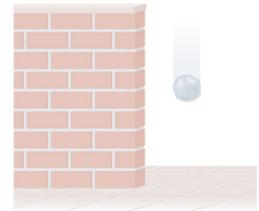
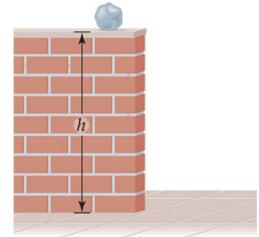
More potential E



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



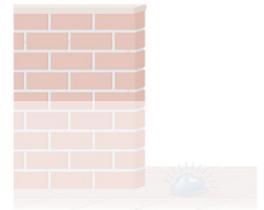
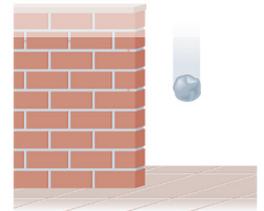
Transferal of Energy

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



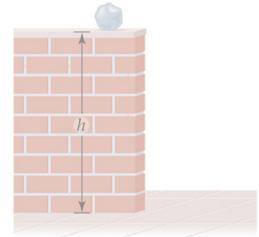
b) As the ball falls,

P.E -----> K. E. ($\frac{1}{2}mv^2$)



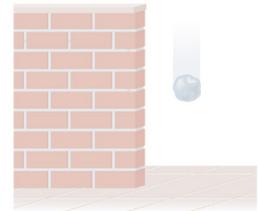
Transferal of Energy

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



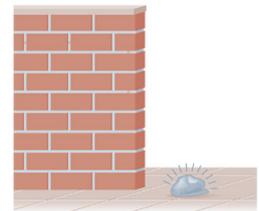
b) As the ball falls,

P.E -----> K. E. ($\frac{1}{2}mv^2$)



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*.

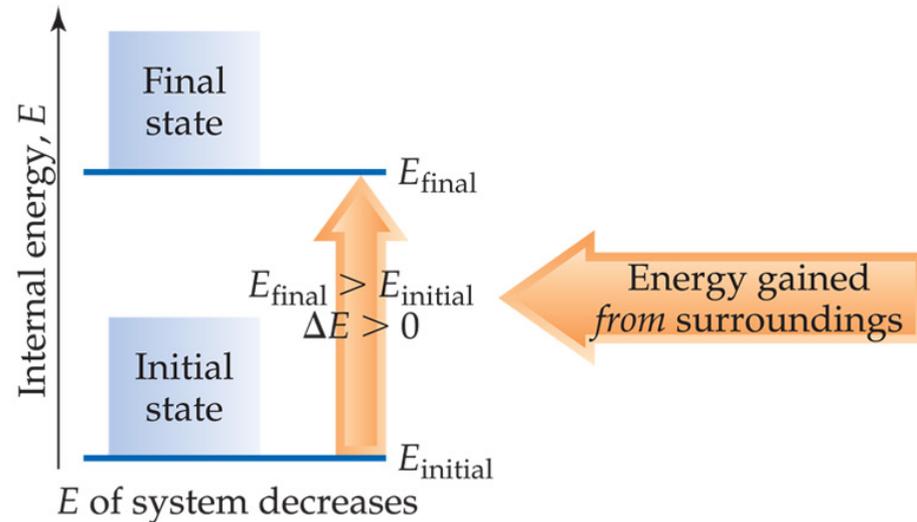
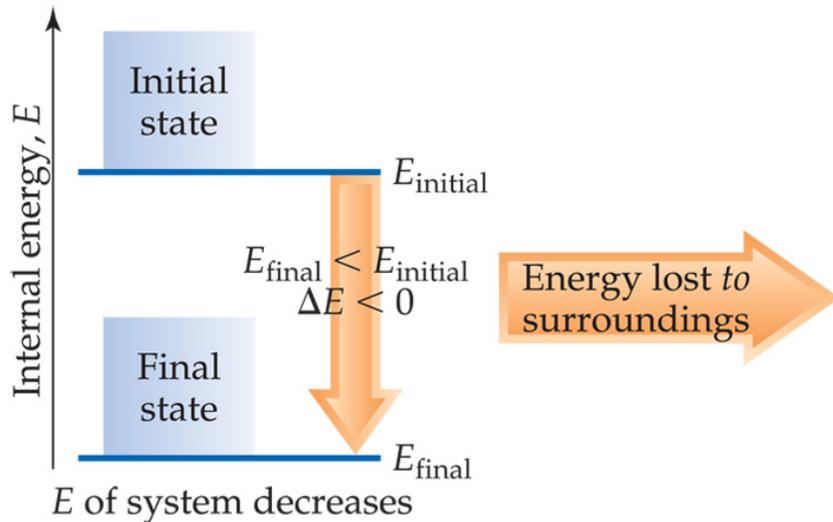
System and Surroundings



- 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; $\Delta E_{\text{System}} = -\Delta E_{\text{surroundings}}$



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 .

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

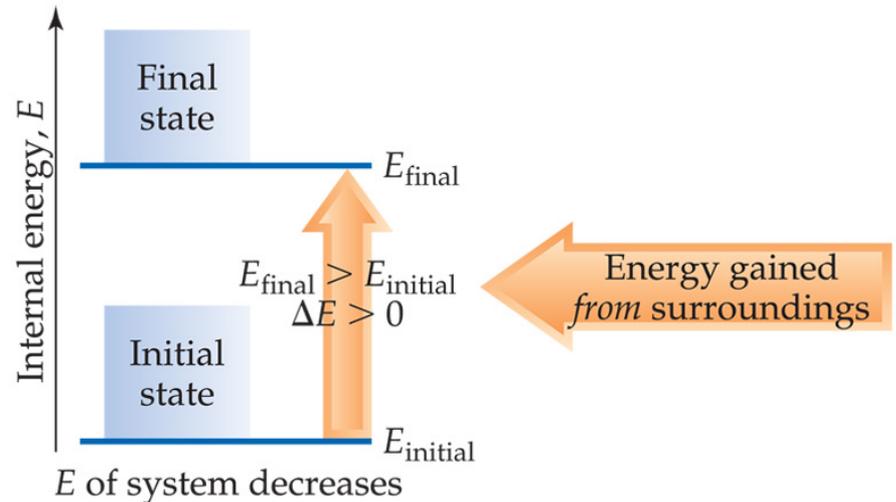
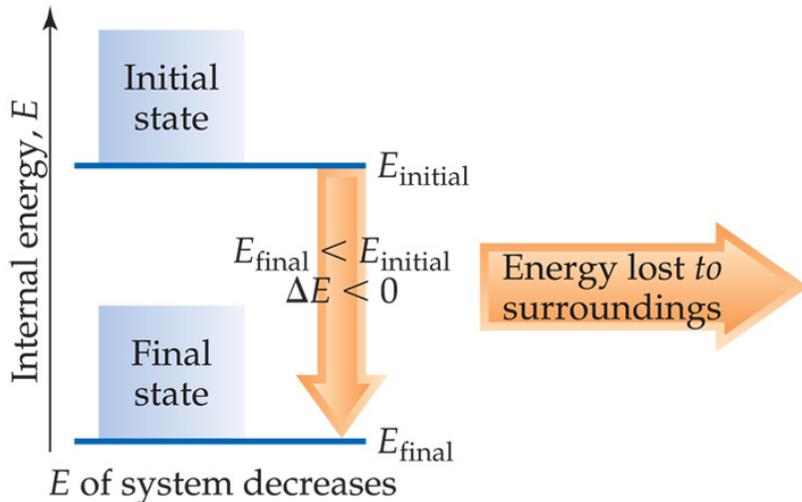
Almost impossible to calculate total internal energy

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

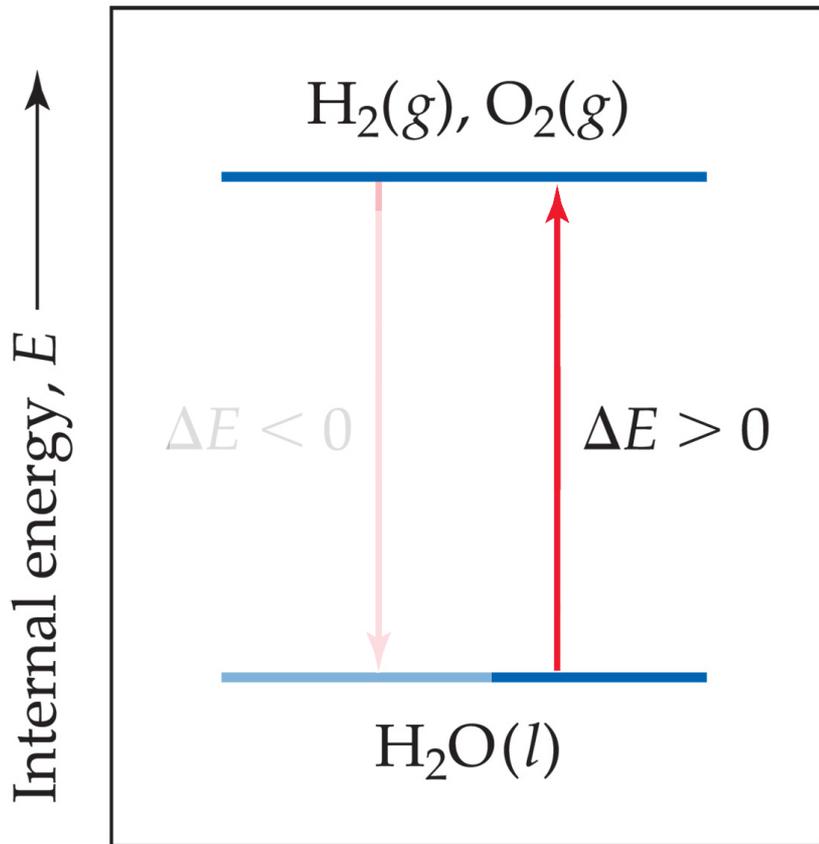
Internal Energy

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

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

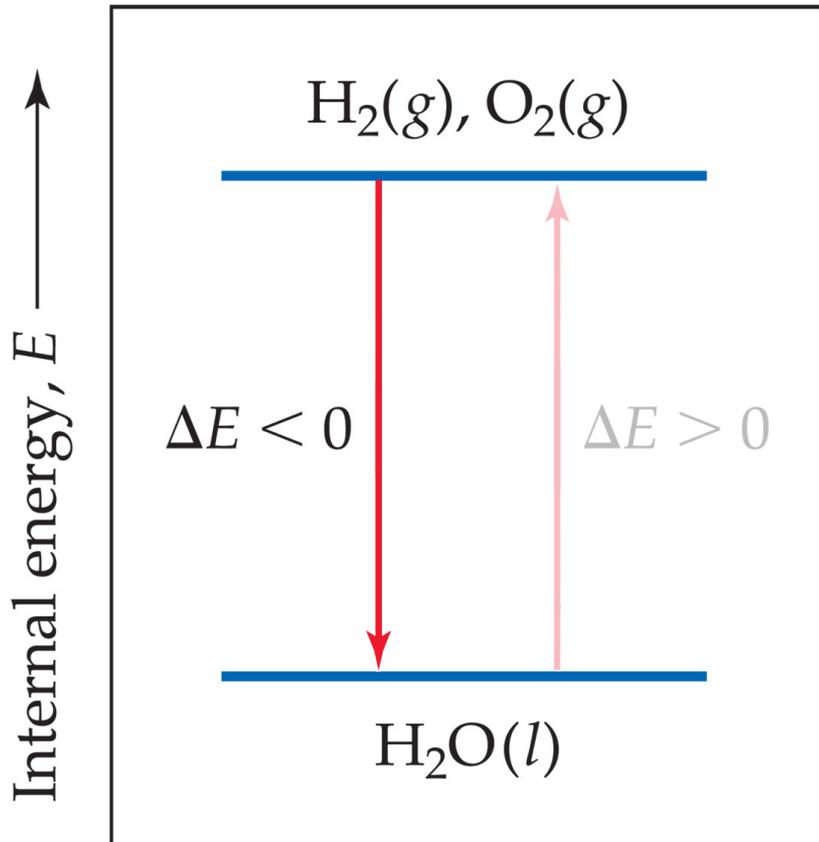


Changes in Internal Energy



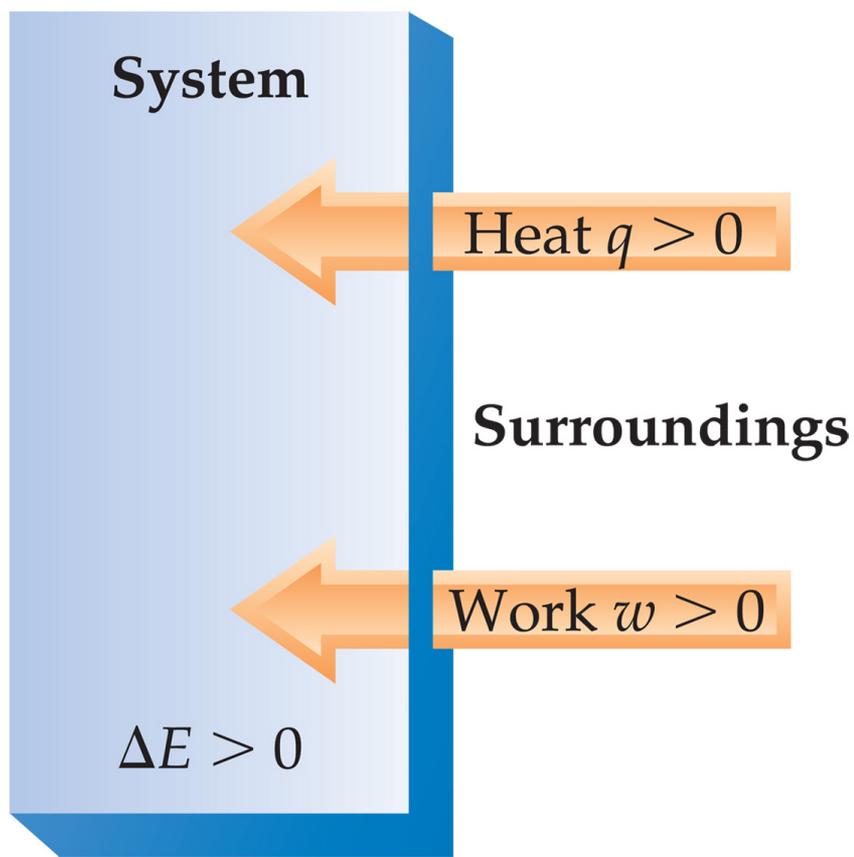
- If $\Delta E > 0$, $E_{\text{final}} > E_{\text{initial}}$
 - Therefore, the system *absorbed* energy from the surroundings.
 - This energy change is called **endergonic**.

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, $\Delta E = q + w$.

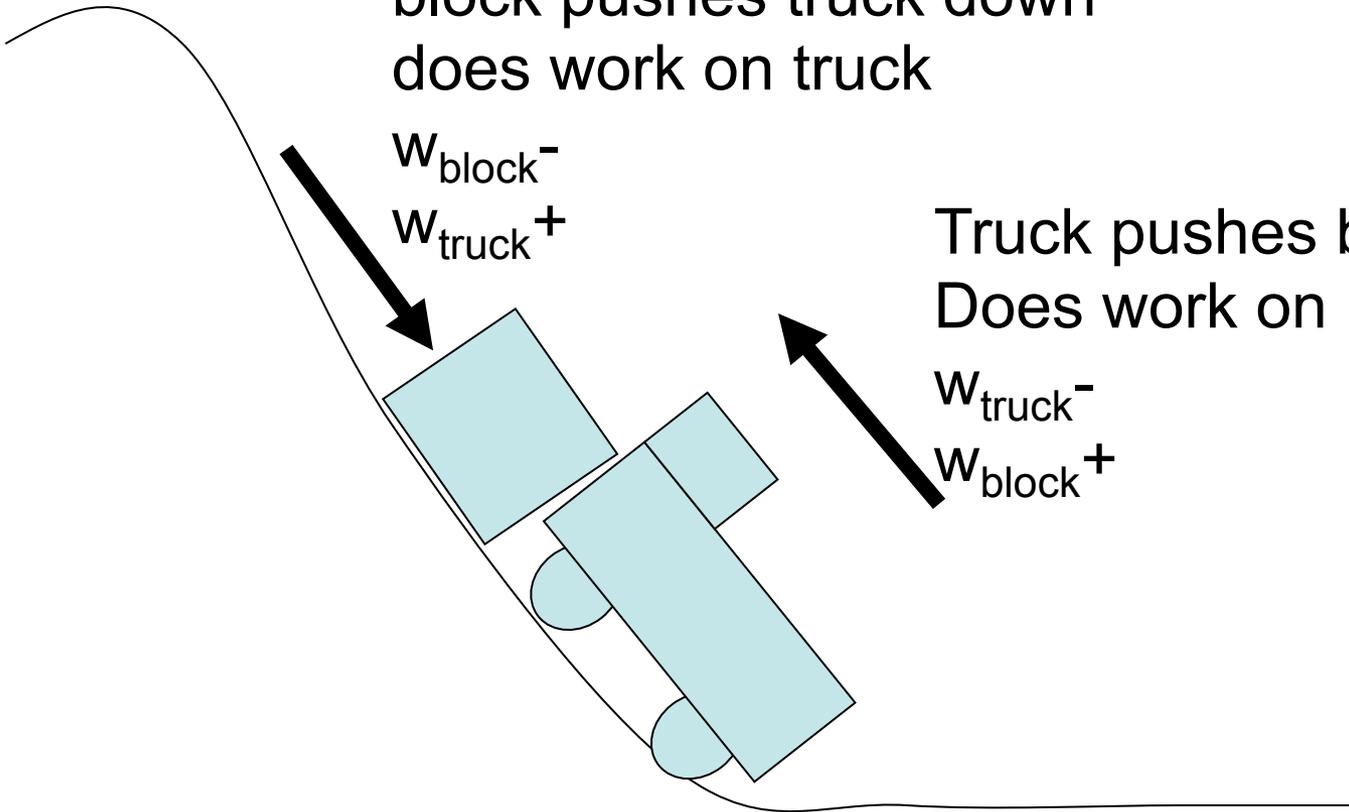
Sign of work

block pushes truck down
does work on truck

$$W_{\text{block}}^-$$
$$W_{\text{truck}}^+$$

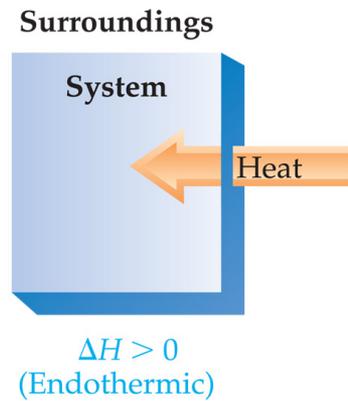
Truck pushes block up.
Does work on block

$$W_{\text{truck}}^-$$
$$W_{\text{block}}^+$$



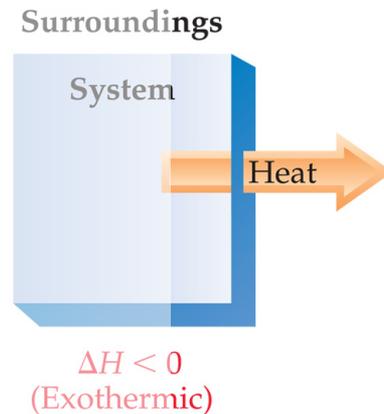
Exchange of Heat between System and Surroundings

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

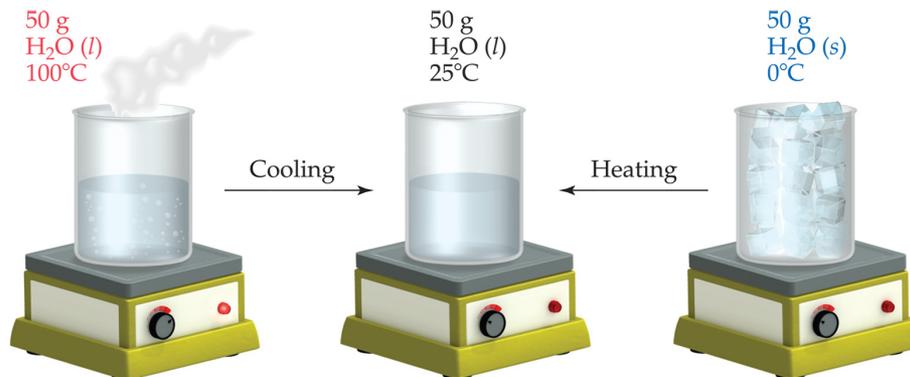


State Functions

Total internal energy of a system:

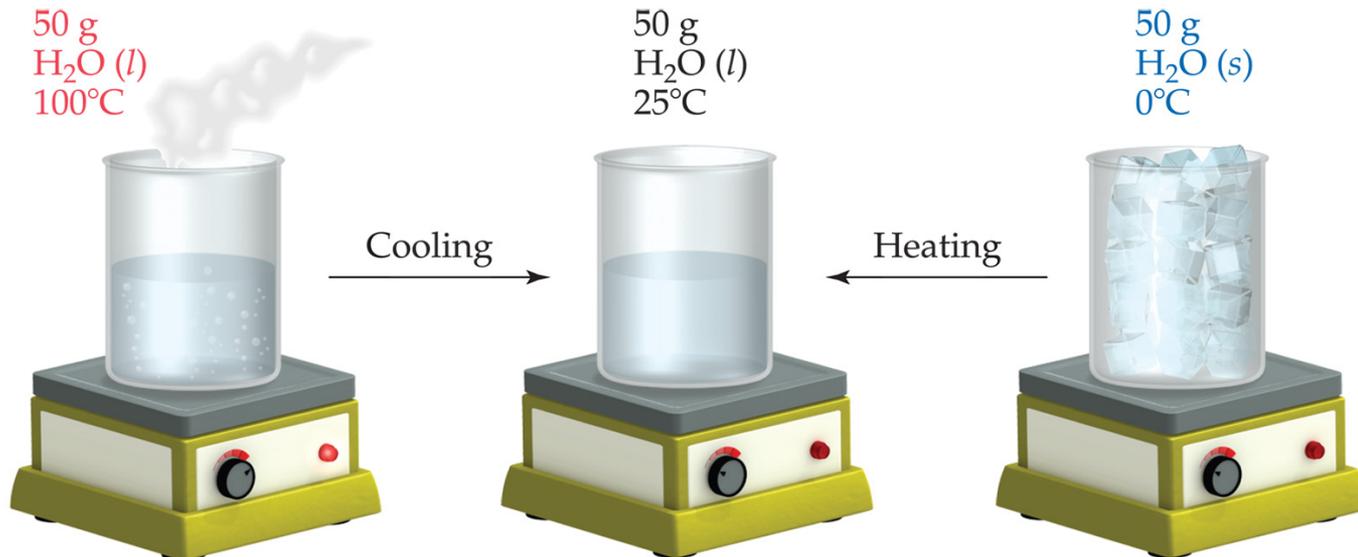
$$\text{K.E.} + E_{\text{electrons}} + E_{\text{nucleus}} + \text{P.E.}_{\text{total}}$$

virtually impossible to measure/calculate



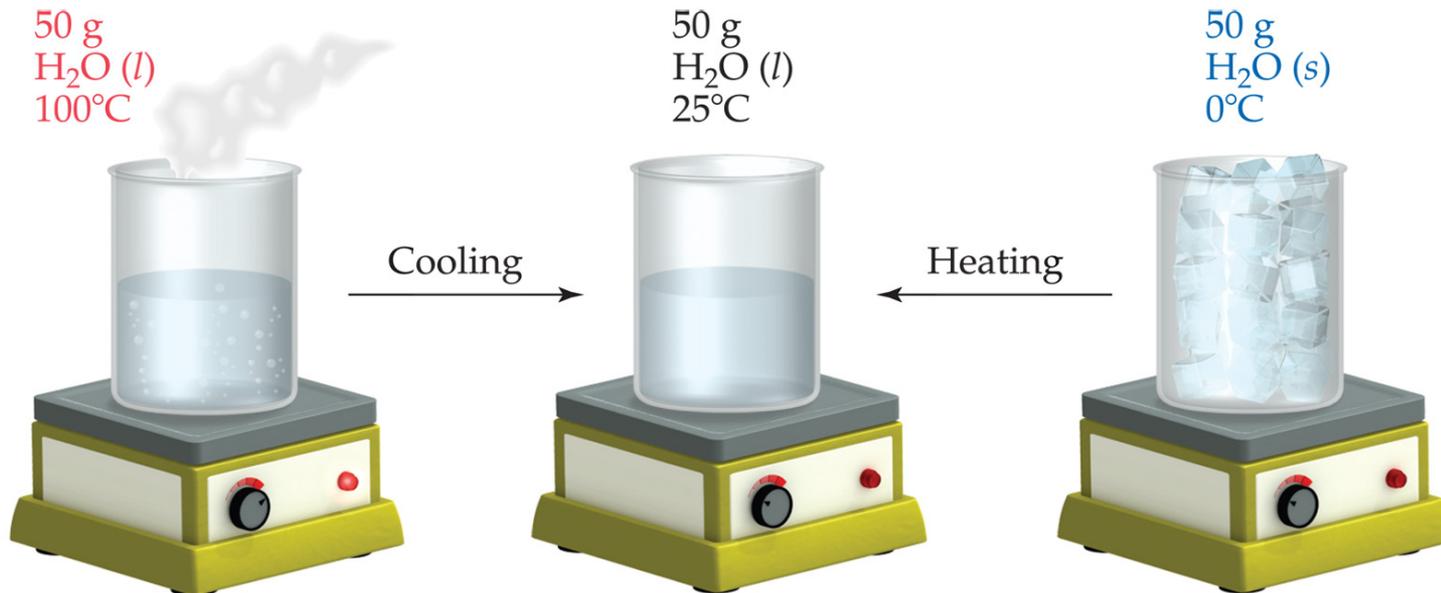
State Functions

- 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.

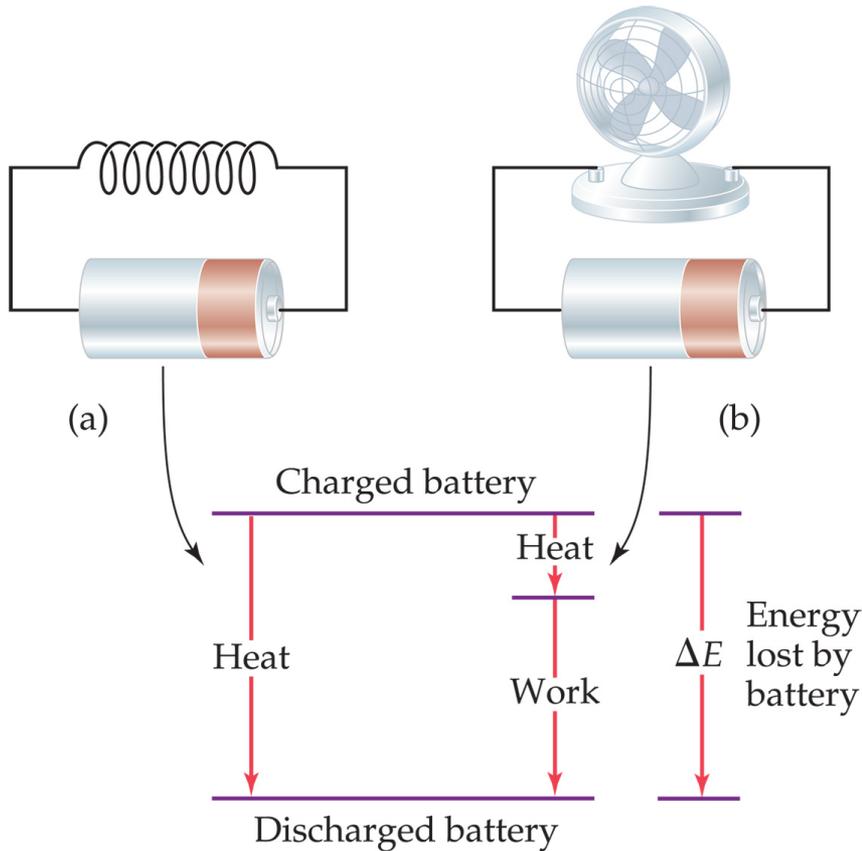


State Functions

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

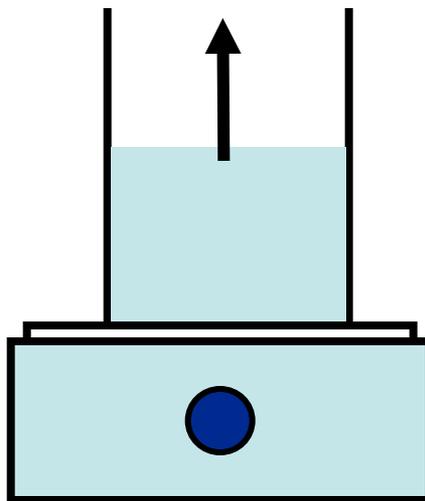


State Functions



- 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.

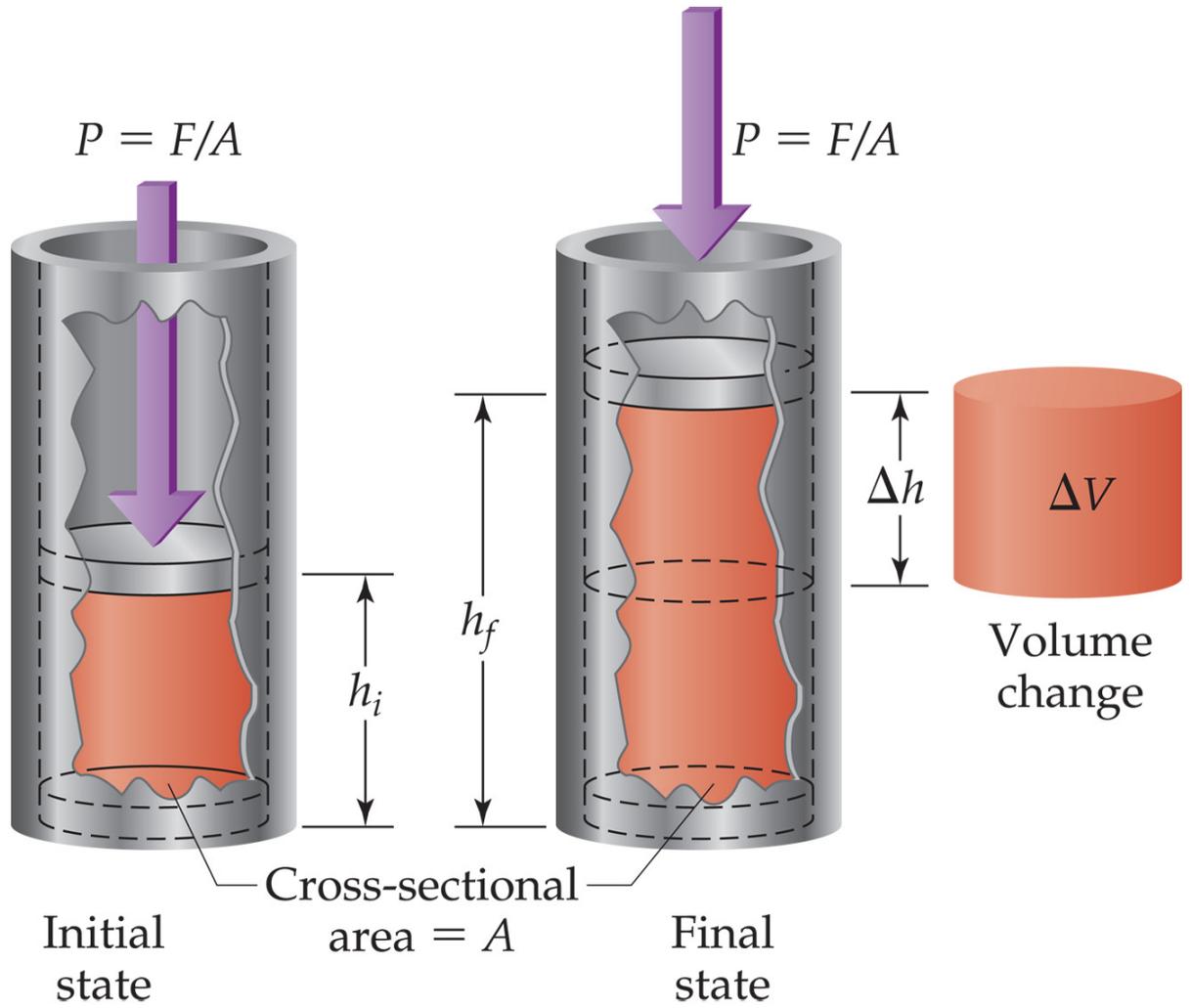
Work



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

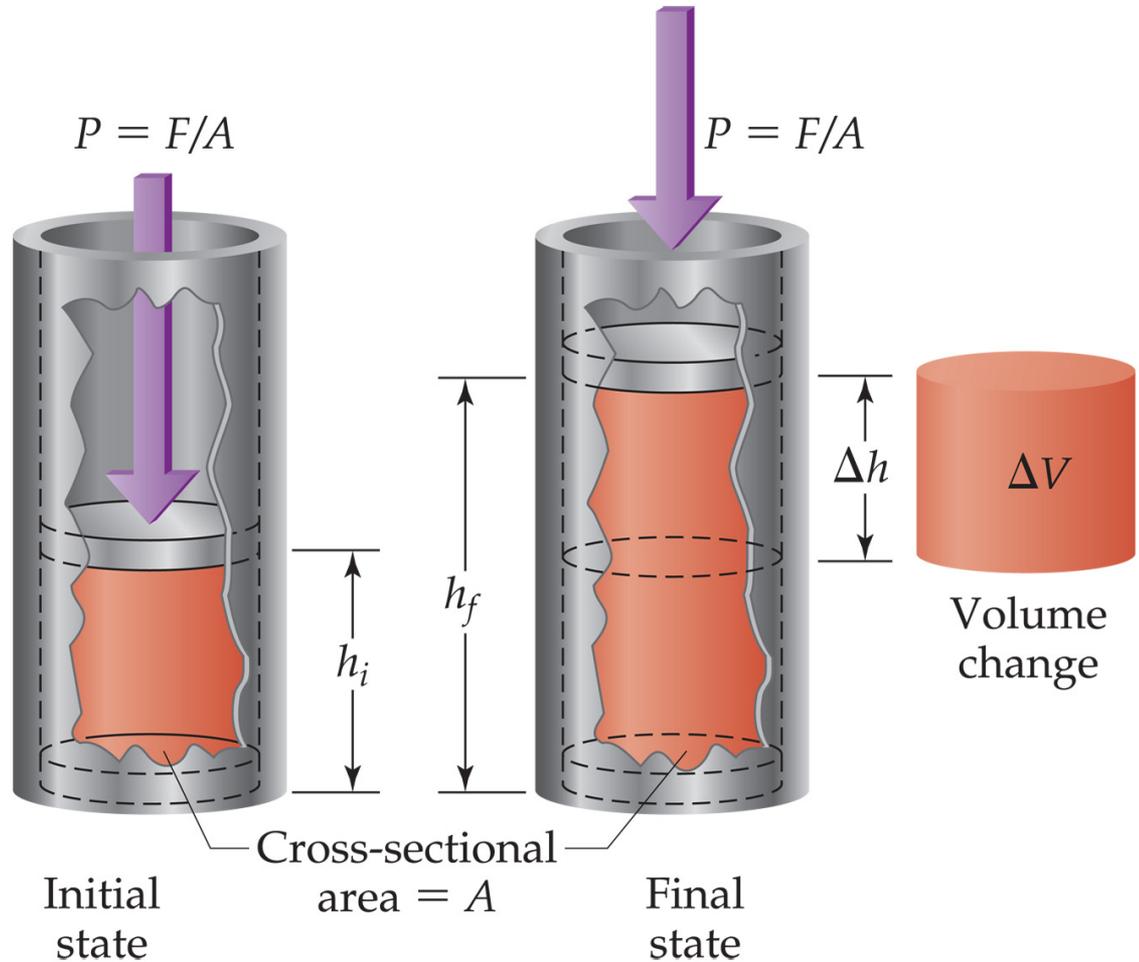
$$w = F \cdot d, \quad F = P \cdot A, \quad d = \Delta h$$

$$w = -P \cdot A \Delta h = -P \Delta V$$

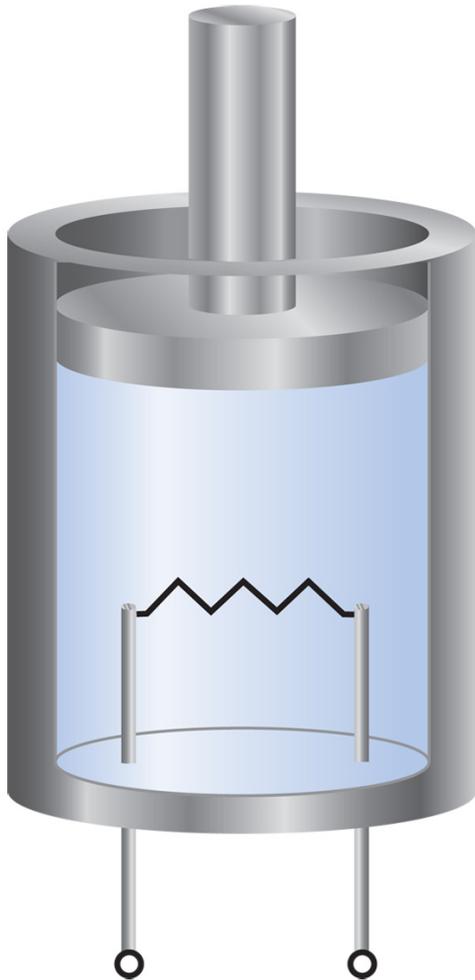
Negative because an **increase** in Volume means that the system is doing work **on** the surroundings.

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

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



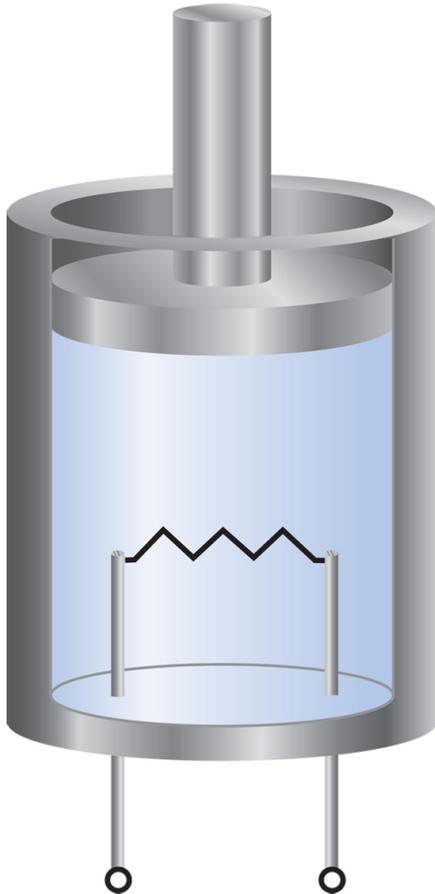
Example



- 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 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?



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

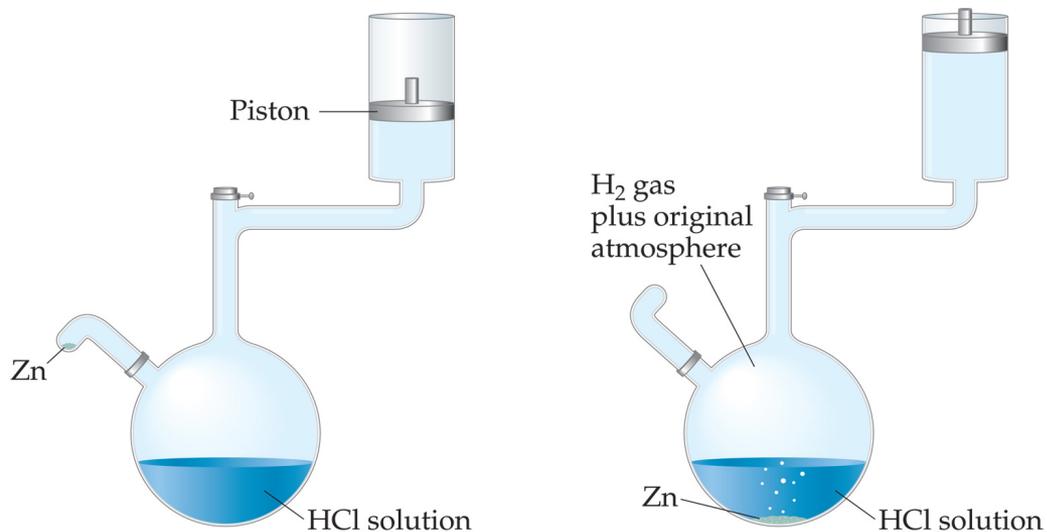
b.2. $w = 0$, q larger

c. ΔE the same & + in each case

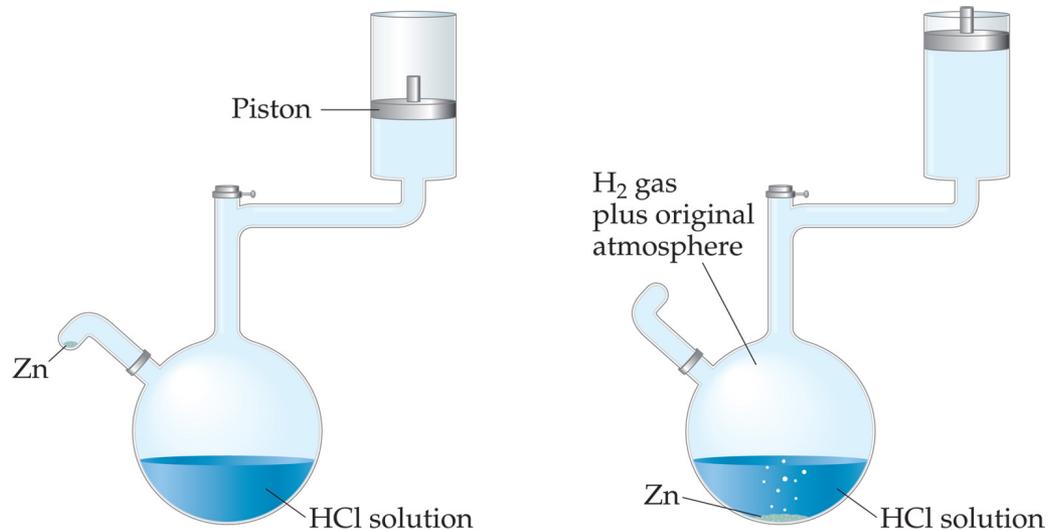
Work

Now we can measure the work:

$$w = -P\Delta V$$

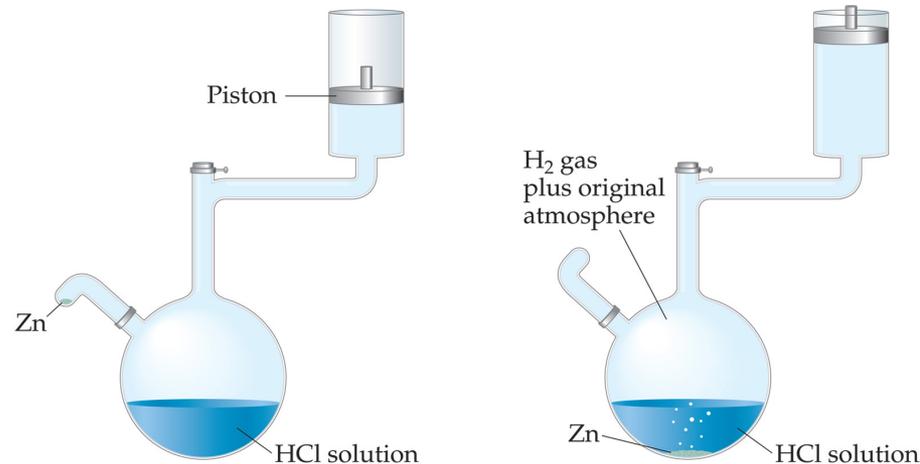


Work

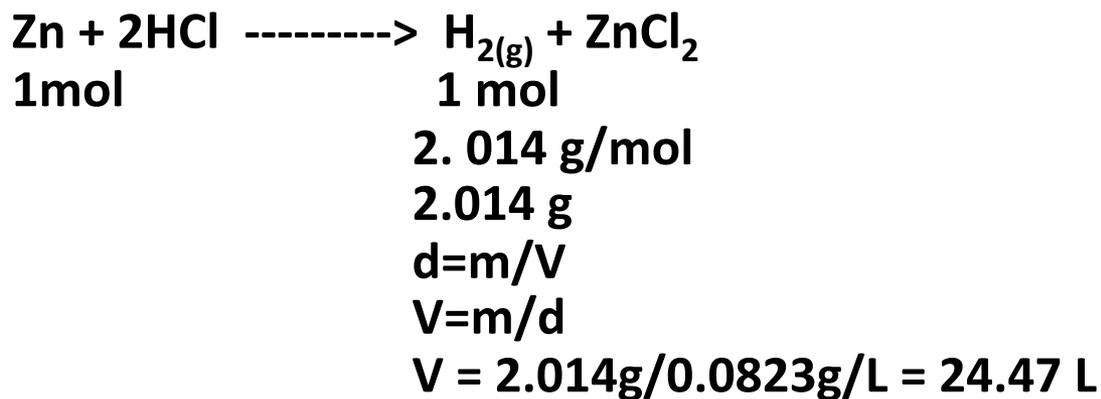


**1 mole of Zn reacts. How much work is done ($P = 1 \text{ atm}$,
density of $\text{H}_2 = 0.0823 \text{ g/L}$)?
1 mole of H_2 is produced.**

Work



1 mole of Zn reacts. How much work is done ($P = 1 \text{ atm}$, density of $\text{H}_2 = 0.0823 \text{ g/L}$)?
1 mole of H_2 is produced.



$$W = -P\Delta V = 1\text{atm}(24.47\text{L}) = -24.47 \text{ L(atm)}$$

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

$$w = \Delta PV.$$

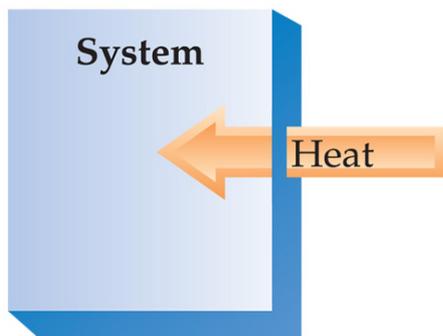
heat flow (q) = H (enthalpy) of system.

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

but only in the right conditions

Endothermic vs. Exothermic

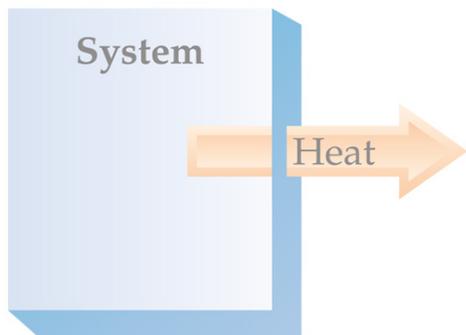
Surroundings



$\Delta H > 0$
(Endothermic)

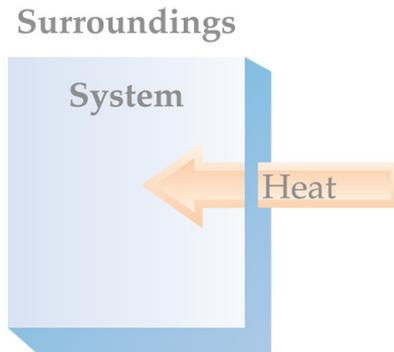
- A process is endothermic when ΔH is positive.

Surroundings

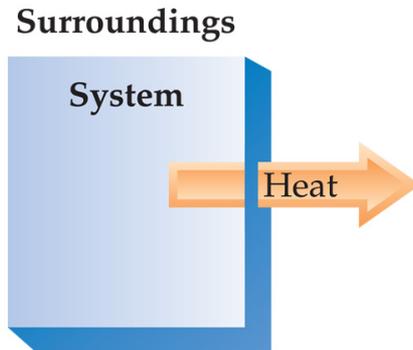


$\Delta H < 0$
(Exothermic)

Endothermicity and Exothermicity



$\Delta H > 0$
(Endothermic)



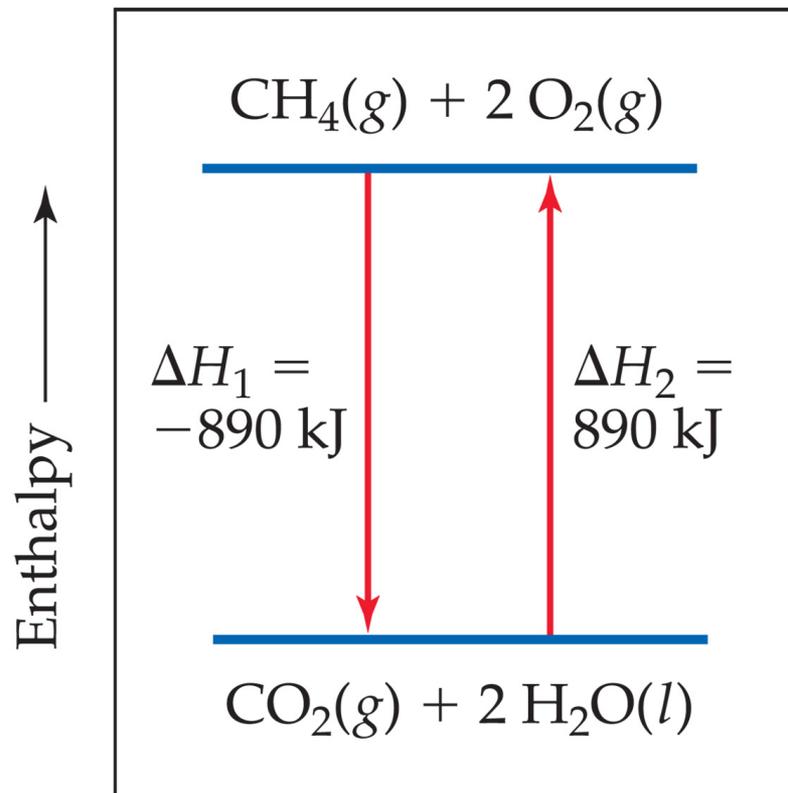
$\Delta H < 0$
(Exothermic)

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

Enthalpies of Reaction

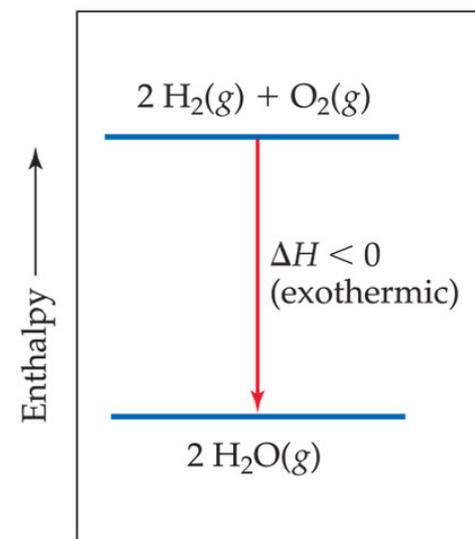
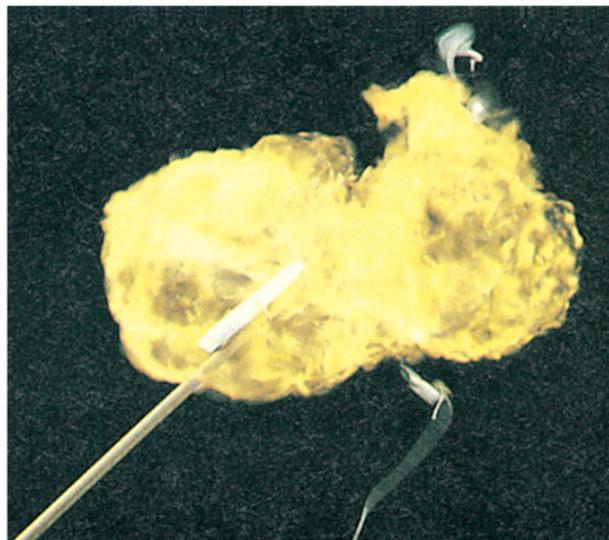
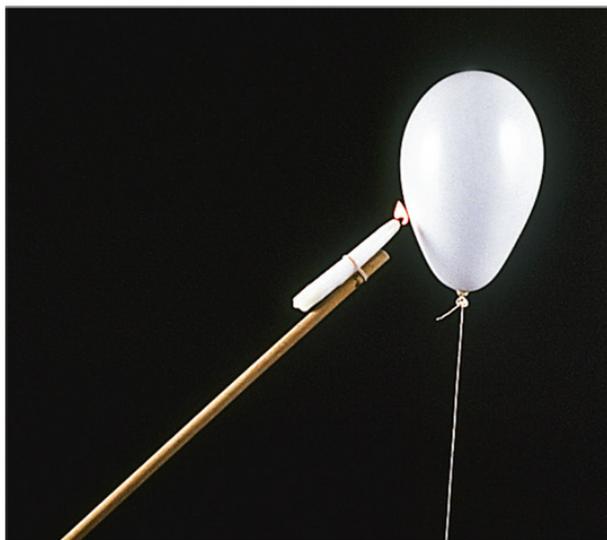
The *change* in enthalpy, ΔH , is the enthalpy of the products minus the enthalpy of the reactants:

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



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:



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

Enthalpy of reaction example

Consider the reaction:

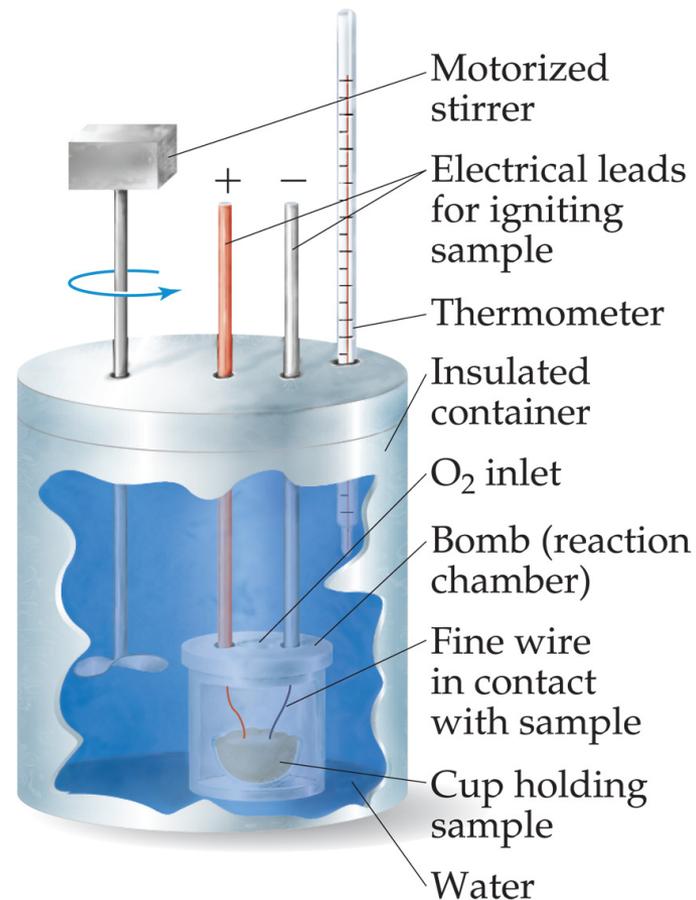
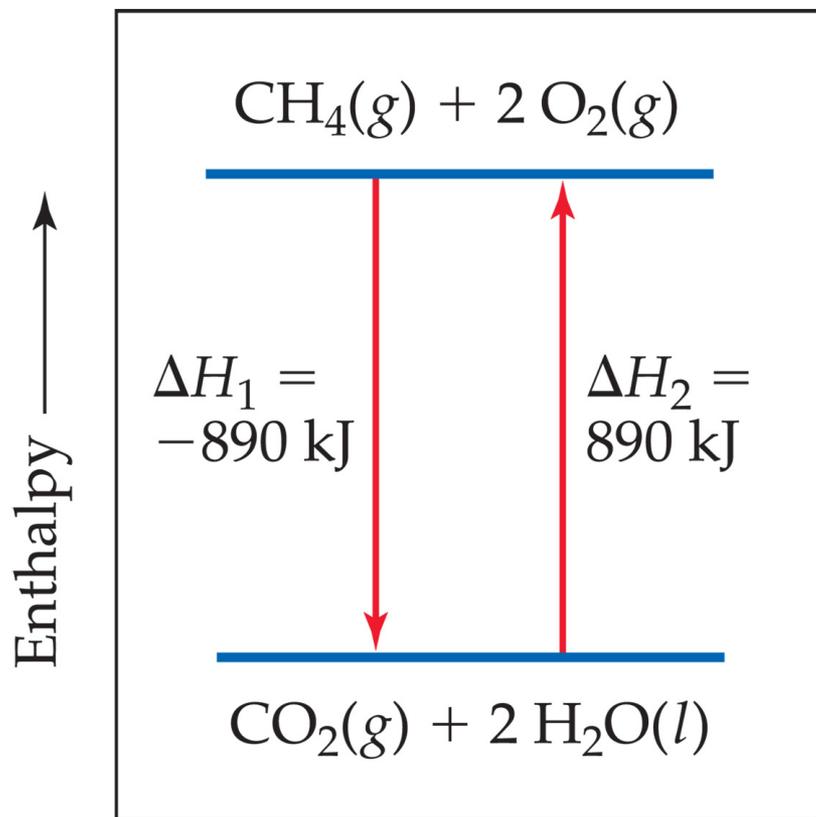


a. What is the enthalpy change for formation of 0.855 moles of O_2 ?



$$\Delta H = -89.4 \text{ kJ}/3 \text{ mol O}_2 (.855 \text{ mol O}_2) = -25.5 \text{ kJ}$$

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 a substance 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:

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

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

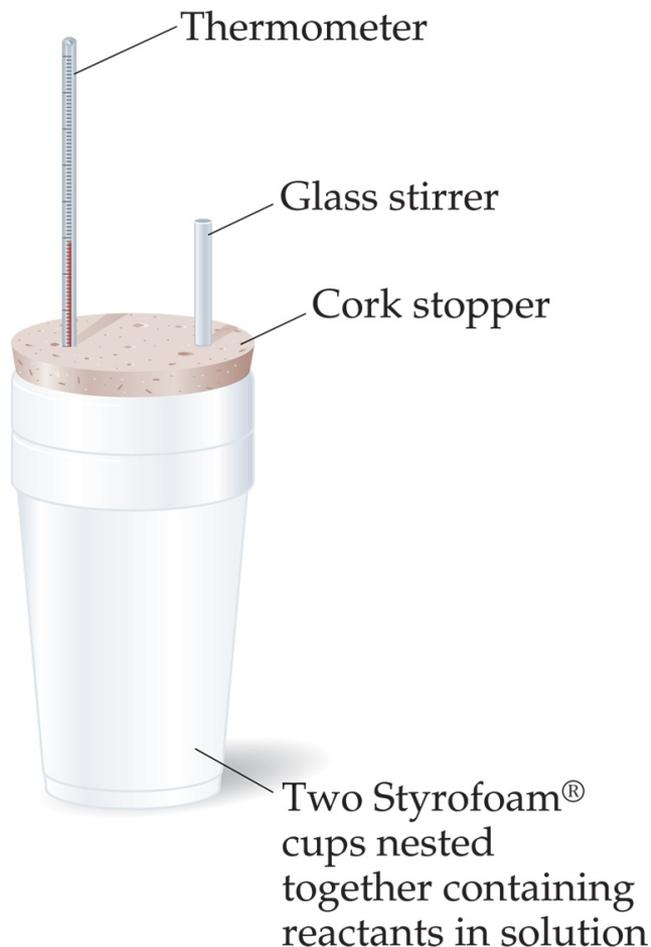
$$sm\Delta T = q$$

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:

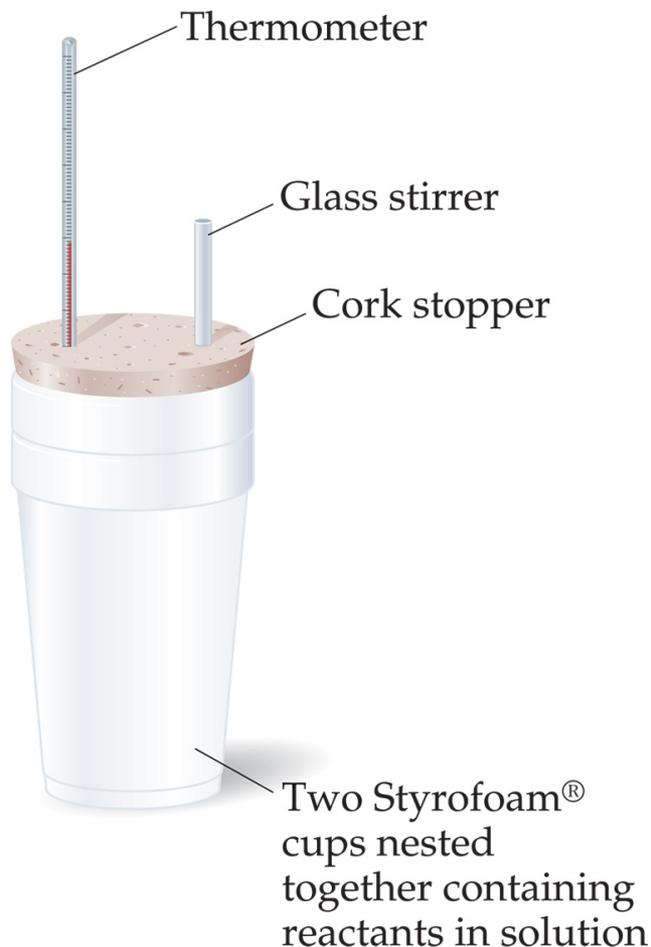
$$q = m \times s \times \Delta T$$

$m = \text{mass}$

$s = \text{specific heat}$

Example

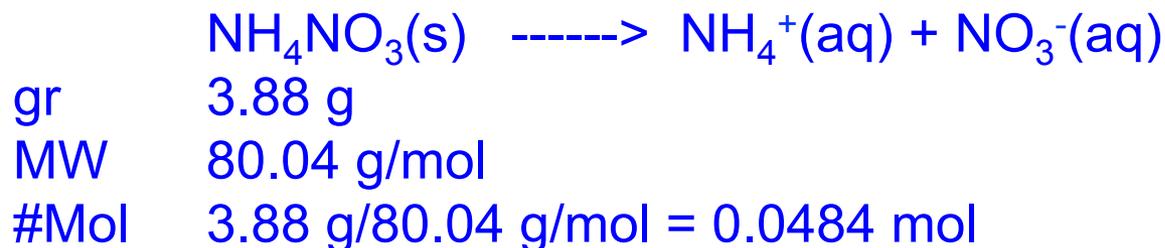
When a 3.88 g sample of solid ammonium nitrate dissolves in 60.0 g of water in a coffee cup calorimeter, the temperature drops from 23.0 °C to 18.4 °C. (a) Calculate ΔH (in kJ/mol ammonium nitrate) for the solution process. Assume that the specific heat is constant and = 1.0 cal/gC. (b) Is this process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



Example

When a 3.88 g sample of solid ammonium nitrate dissolves 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:



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

System: Solid AmNO_3

Surroundings: Solution

$$q = s(\text{specific heat})m(\text{mass})\Delta T$$

$$q = s(\text{J/g}^\circ\text{C})m(\text{grams})(T_{\text{final}} - T_{\text{initial}})$$

$$q_{\text{solution}} = 4.184(\text{J/g}^\circ\text{C})(63.88 \text{ g})(18.4^\circ\text{C} - 23.0^\circ\text{C}) = -1229 \text{ J}$$

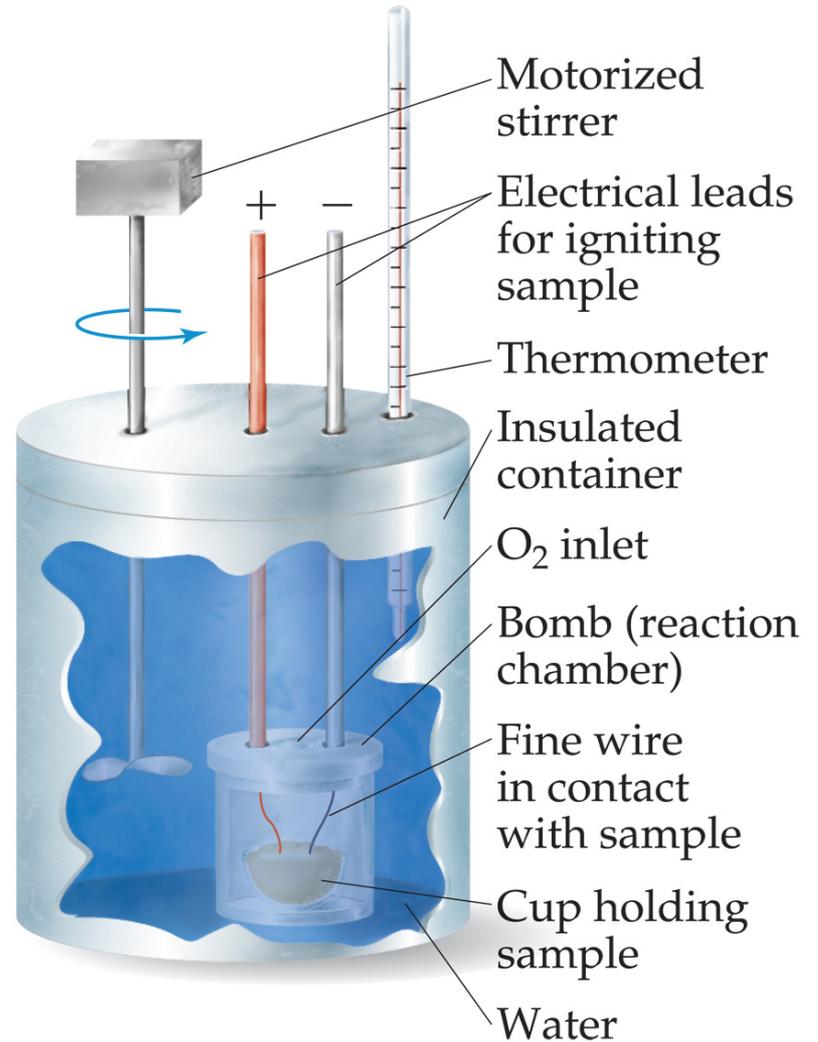
$$q_{\text{water}} = -q_{\text{ammonium nitrate}} = +1229 \text{ J}$$

$$\Delta H(\text{per mol } \text{NH}_4\text{NO}_3) = 1.229 \text{ kJ}/.0484 \text{ mol} = 25.39 \text{ kJ/mol}$$

(b) Endothermic

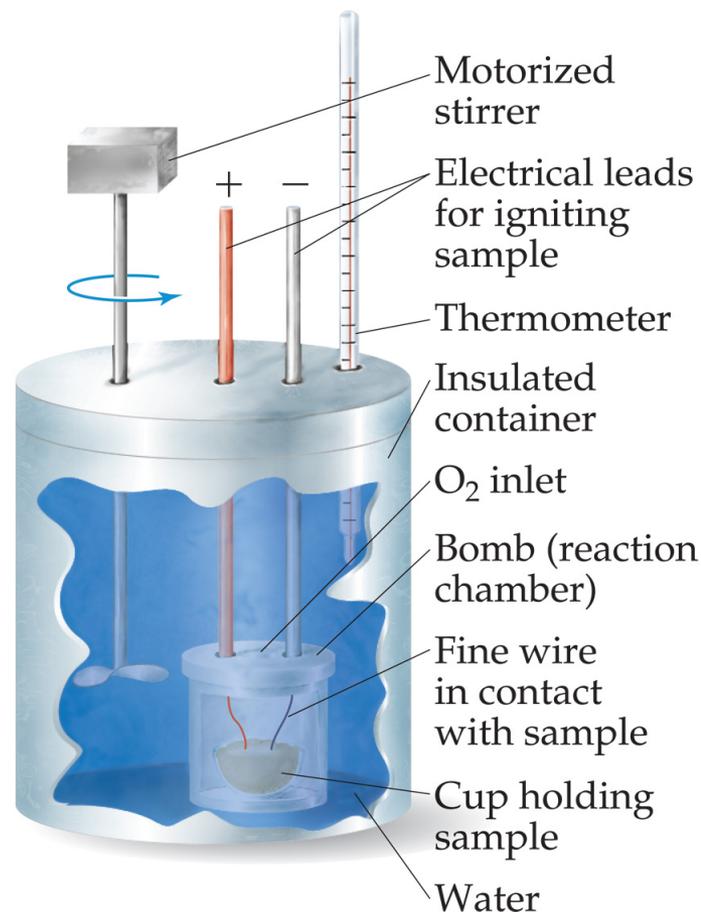
Bomb Calorimetry

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.
- $q_{\text{surroundings}} = C\Delta T = 10 \text{ kJ/}^\circ\text{C}(100 \text{ }^\circ\text{C}) = 1000 \text{ kJ}$
- $q_{\text{surroundings}} = -q_{\text{system}}$
- $q_{\text{system}} = -1000$
- $1000 \text{ kJ}/50\text{g} = 20 \text{ kJ/g}$
- **Does $\Delta E = \Delta H$ in this case?**

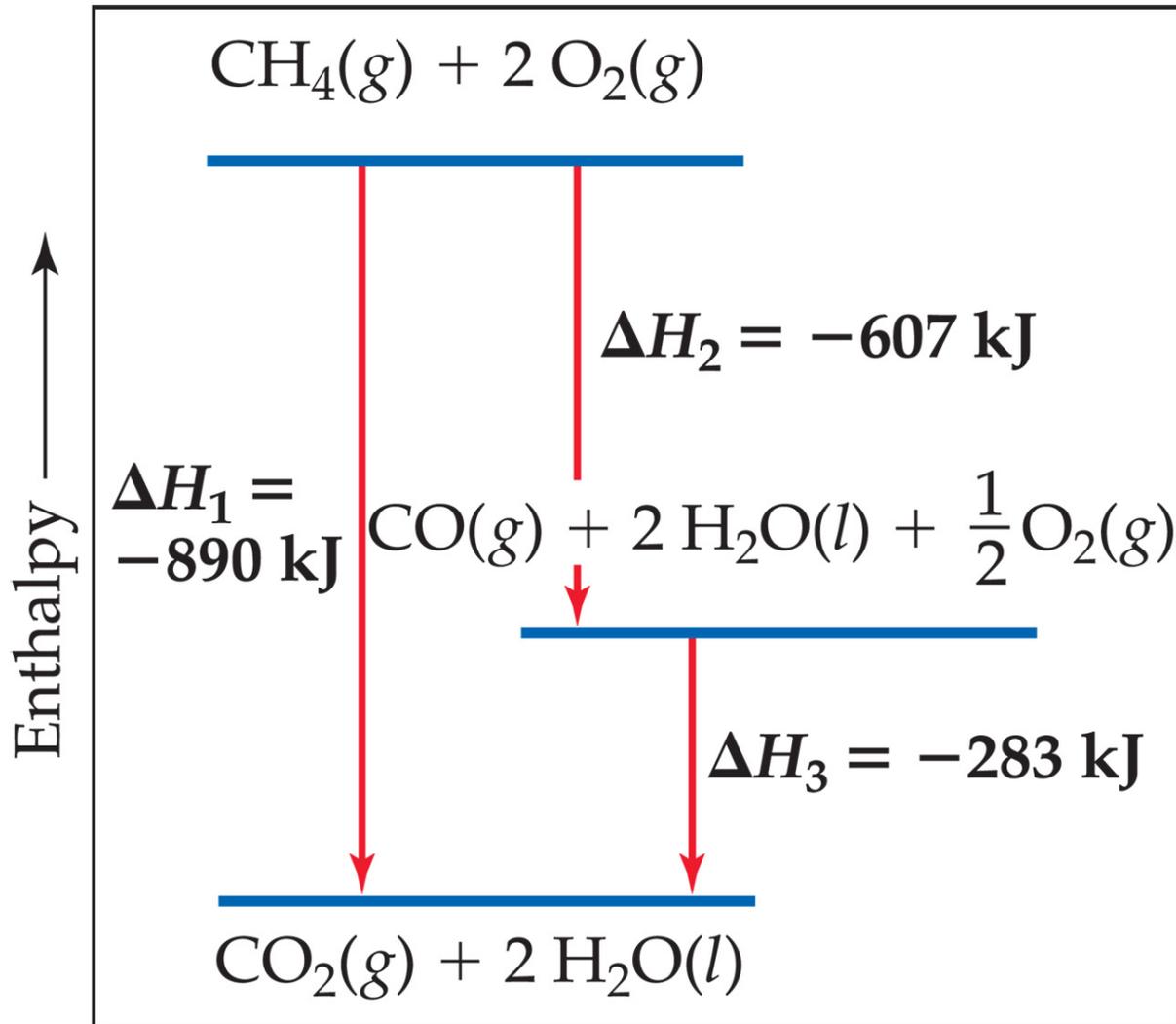
Example

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

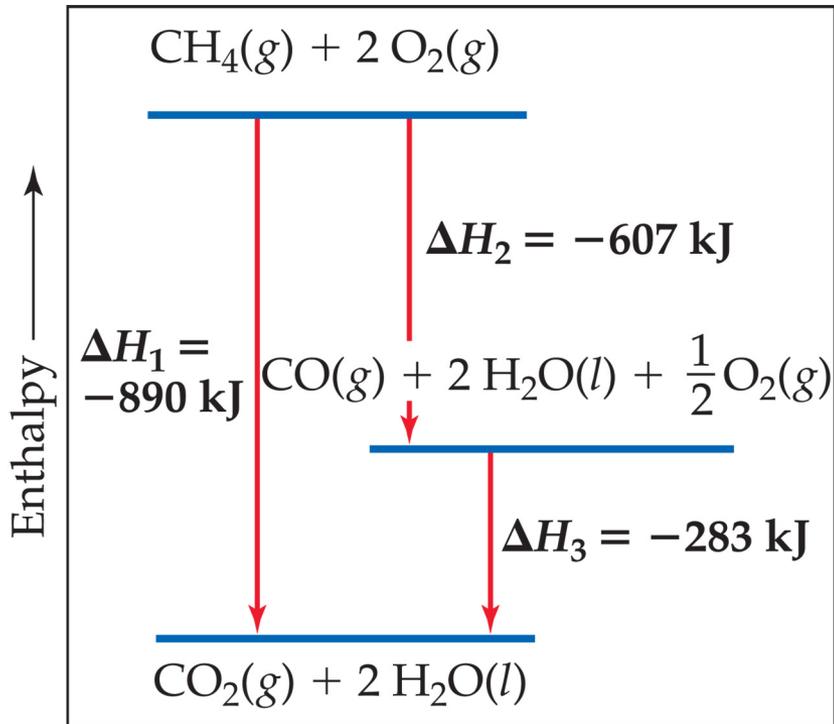


Yes!

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:
- $\text{N}_2(\text{g}) + \text{O}_2(\text{g}) \text{ ----> } 2\text{NO}(\text{g}) \quad \Delta\text{H} = 180.7 \text{ kJ}$
- $2\text{NO}(\text{g}) + \text{O}_2(\text{g}) \text{ ----> } 2\text{NO}_2(\text{g}) \quad \Delta\text{H} = -113.1 \text{ kJ}$
- $2\text{N}_2\text{O}(\text{g}) \text{ ----> } 2\text{N}_2(\text{g}) + \text{O}_2(\text{g}) \quad \Delta\text{H} = -163.2 \text{ kJ}$
- use Hess' s law to calculate ΔH for the reaction:
- $\text{N}_2\text{O}(\text{g}) + \text{NO}_2(\text{g}) \text{ ----> } 3\text{NO}(\text{g})$

Hess' s law, example:

• Given:



• use Hess' s law to calculate ΔH for the reaction:



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 elemental forms.

That's what we did for the Thermite reaction:



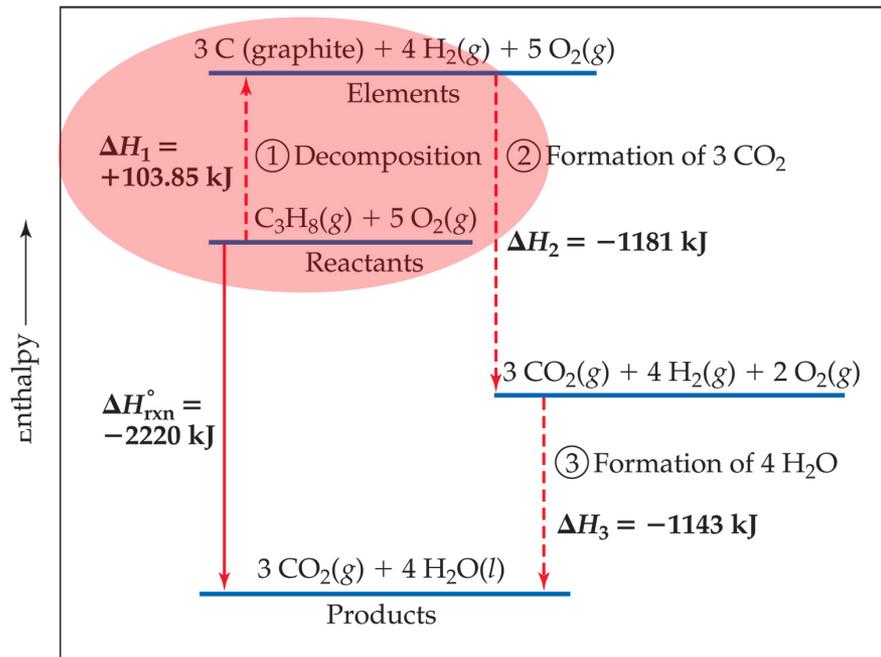
•What is the heat of reaction given:



Calculation of ΔH



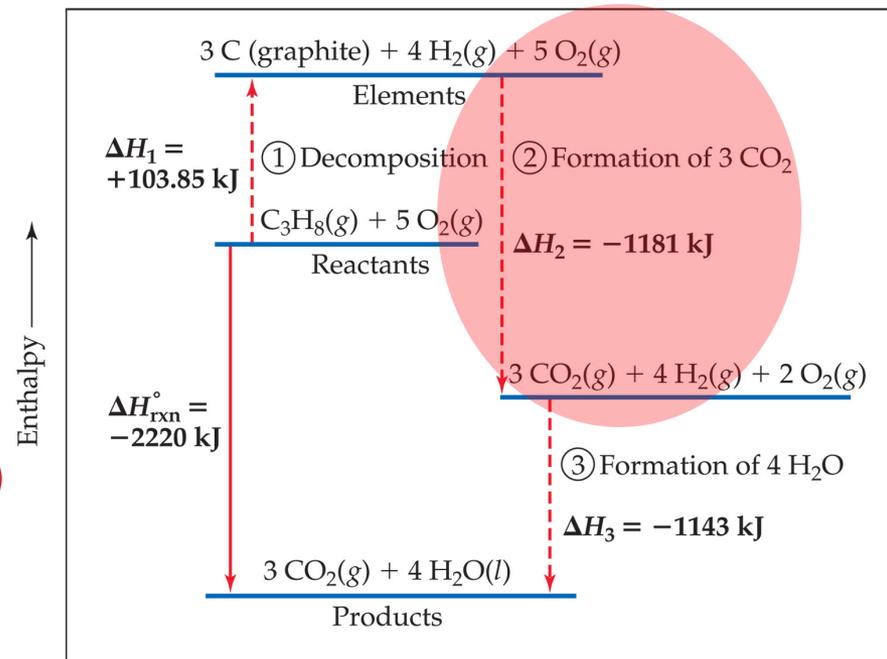
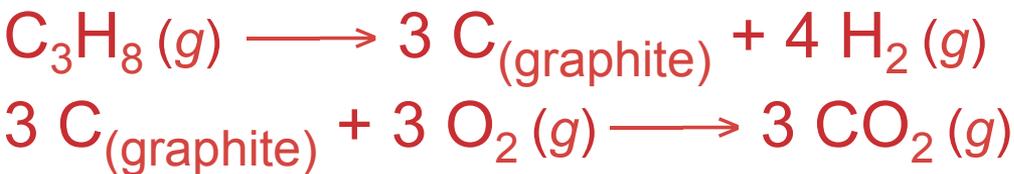
- Imagine this as occurring in 3 steps:



Calculation of ΔH



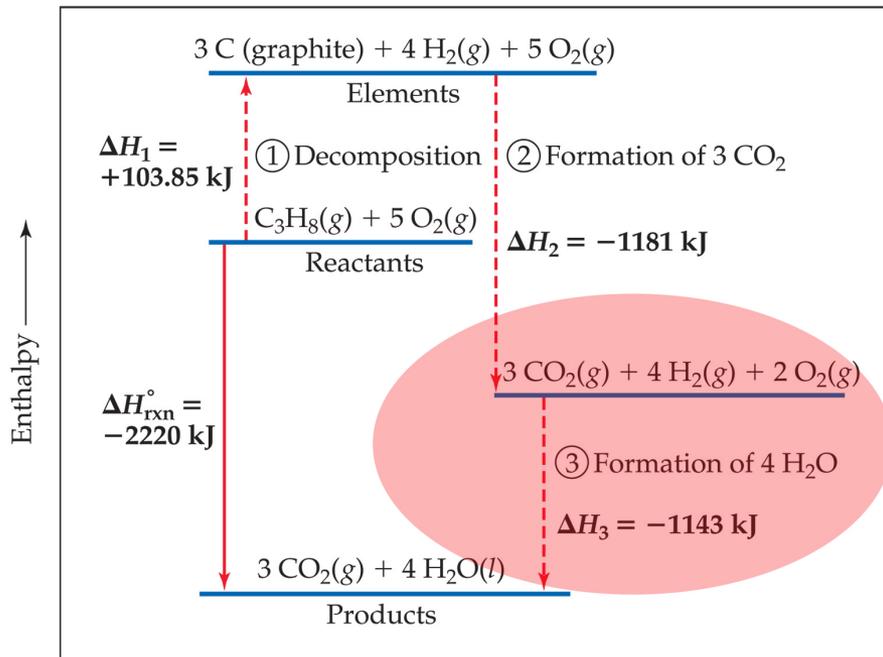
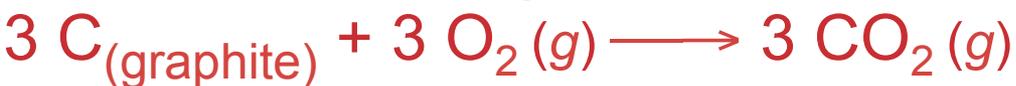
- Imagine this as occurring in 3 steps:



Calculation of ΔH



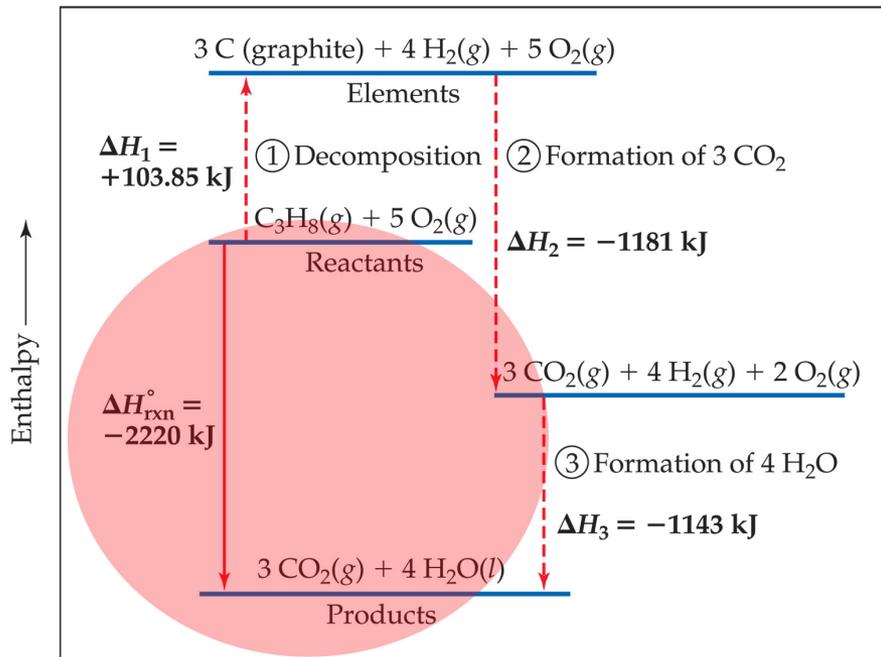
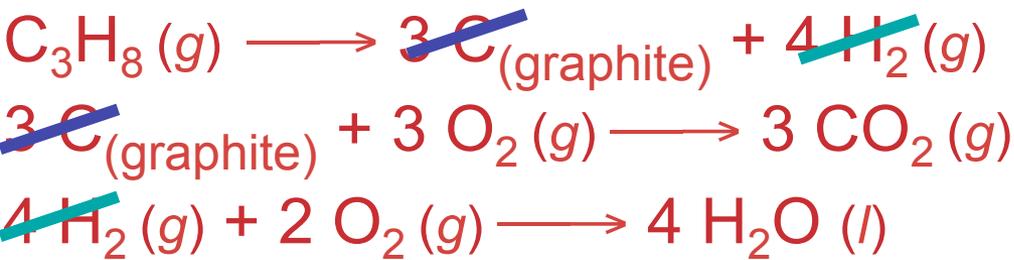
- Imagine this as occurring in 3 steps:



Calculation of ΔH



- The sum of these equations is:



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:

$$\Delta H = \sum n \Delta H_{f(\text{products})}^{\circ} - \sum m \Delta H_{f(\text{reactants})}^{\circ}$$

where n and m are the stoichiometric coefficients.

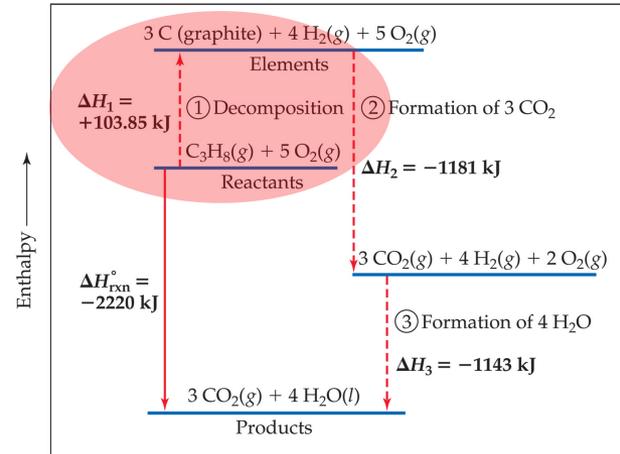
Standard Enthalpies of Formation

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:
- $\text{C}_3\text{H}_8 + 5 \text{O}_2 \rightarrow 3\text{CO}_2 + 4\text{H}_2\text{O}$

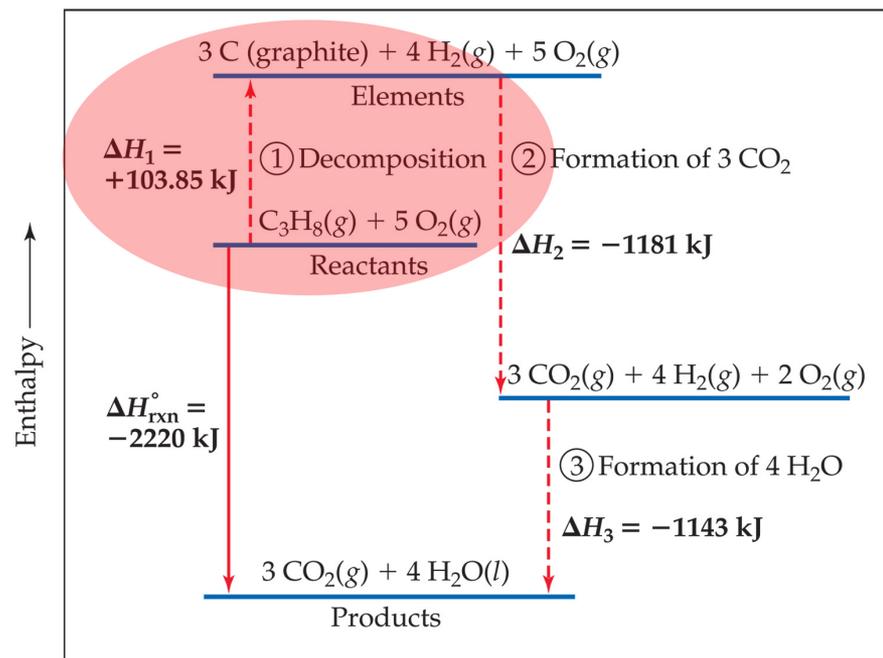


Substance	Formula	ΔH_f° (kJ/mol)	Substance	Formula	ΔH_f° (kJ/mol)
Acetylene	$\text{C}_2\text{H}_2(\text{g})$	226.7	Hydrogen chloride	$\text{HCl}(\text{g})$	-92.30
Ammonia	$\text{NH}_3(\text{g})$	-46.19	Hydrogen fluoride	$\text{HF}(\text{g})$	-268.60
Benzene	$\text{C}_6\text{H}_6(\text{l})$	49.0	Hydrogen iodide	$\text{HI}(\text{g})$	25.9
Calcium carbonate	$\text{CaCO}_3(\text{s})$	-1207.1	Methane	$\text{CH}_4(\text{g})$	-74.80
Calcium oxide	$\text{CaO}(\text{s})$	-635.5	Methanol	$\text{CH}_3\text{OH}(\text{l})$	-238.6
Carbon dioxide	$\text{CO}_2(\text{g})$	-393.5	Propane	$\text{C}_3\text{H}_8(\text{g})$	-103.85
Carbon monoxide	$\text{CO}(\text{g})$	-110.5	Silver chloride	$\text{AgCl}(\text{s})$	-127.0
Diamond	$\text{C}(\text{s})$	1.88	Sodium bicarbonate	$\text{NaHCO}_3(\text{s})$	-947.7
Ethane	$\text{C}_2\text{H}_6(\text{g})$	-84.68	Sodium carbonate	$\text{Na}_2\text{CO}_3(\text{s})$ 1	-130.9
Ethanol	$\text{C}_2\text{H}_5\text{OH}(\text{l})$	-277.7	Sodium chloride	$\text{NaCl}(\text{s})$	-410.9
Ethylene	$\text{C}_2\text{H}_4(\text{g})$	52.30	Sucrose	$\text{C}_{12}\text{H}_{22}\text{O}_{11}(\text{s})$	-2221
Glucose	$\text{C}_6\text{H}_{12}\text{O}_6(\text{s})$	-1273	Water	$\text{H}_2\text{O}(\text{l})$	-285.8
Hydrogen bromide	$\text{HBr}(\text{g})$	-36.23	Water vapor	$\text{H}_2\text{O}(\text{g})$	-241.8

Calculation of ΔH



$$\begin{aligned}\Delta H &= [3(\Delta H_f \text{CO}_2) + 4(\Delta H_f \text{H}_2\text{O})] - [(\Delta H_f \text{C}_3\text{H}_8) + (5\Delta H_f \text{O}_2)] \\ &= [3(-393.5 \text{ kJ}) + 4(-285.8 \text{ kJ})] - [(-103.85 \text{ kJ}) + 5(0)] \\ &= [-1180.5 \text{ kJ} + (-1143.2 \text{ kJ})] - [(-103.85 \text{ kJ}) + 0 \text{ kJ}] \\ &= [-2323.7 \text{ kJ}] - [-103.85 \text{ kJ}] \\ &= -2219.9 \text{ kJ}\end{aligned}$$



Energy in Foods

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

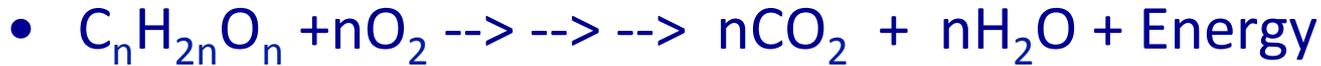
TABLE 5.4 Compositions and Fuel Values of Some Common Foods

	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

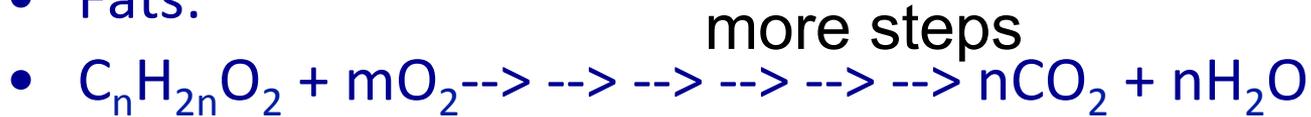
*Beers typically contain 3.5% ethanol, which has fuel value.

What's the deal with fat?

- Carbohydrates:



- Fats:



Fat storage.

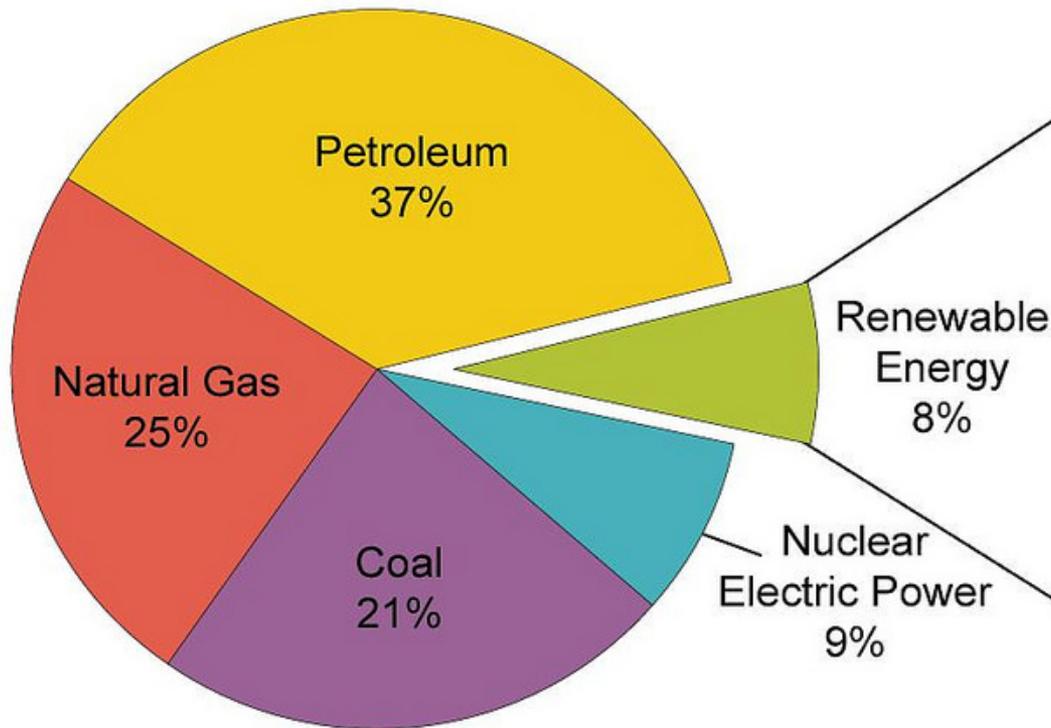
It also clogs your arteries.

Fuels

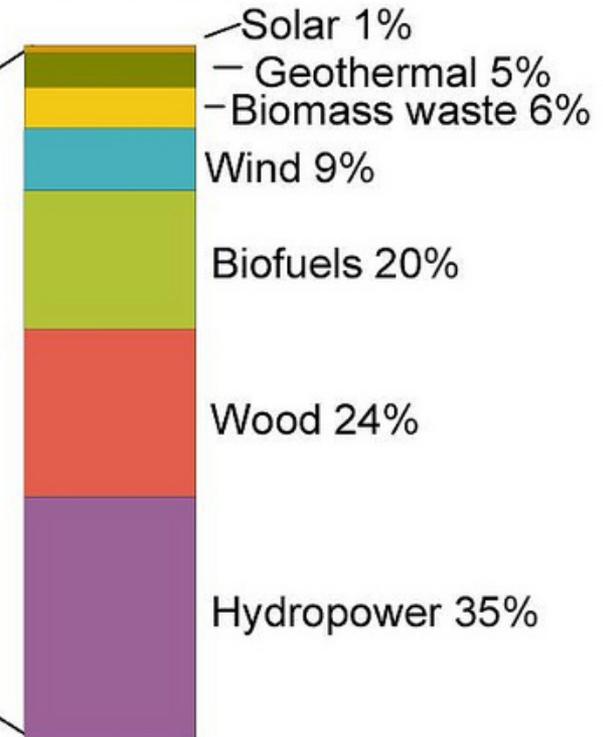
The vast majority of the energy consumed in this country comes from fossil fuels.

U.S. Energy Consumption by Energy Source, 2009

Total = 94.578 Quadrillion Btu



Total = 7.744 Quadrillion Btu



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).

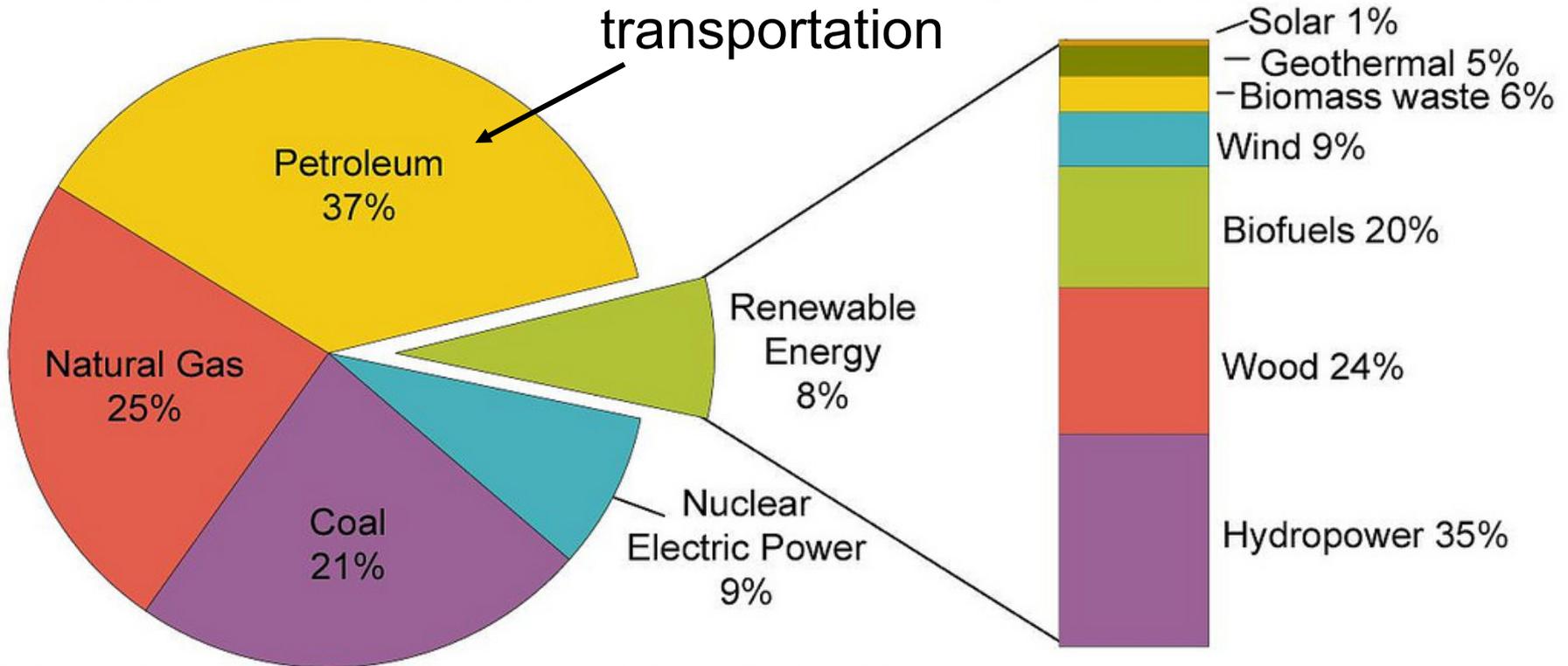
Major issues

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

U.S. Energy Consumption by Energy Source, 2009

Total = 94.578 Quadrillion Btu

Total = 7.744 Quadrillion Btu



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 problem with oil

- Not “renewable” (will run out)
- Pollution (combustion not perfect).
- Global warming
CO₂ absorbs heat.



Efficiency/conservation

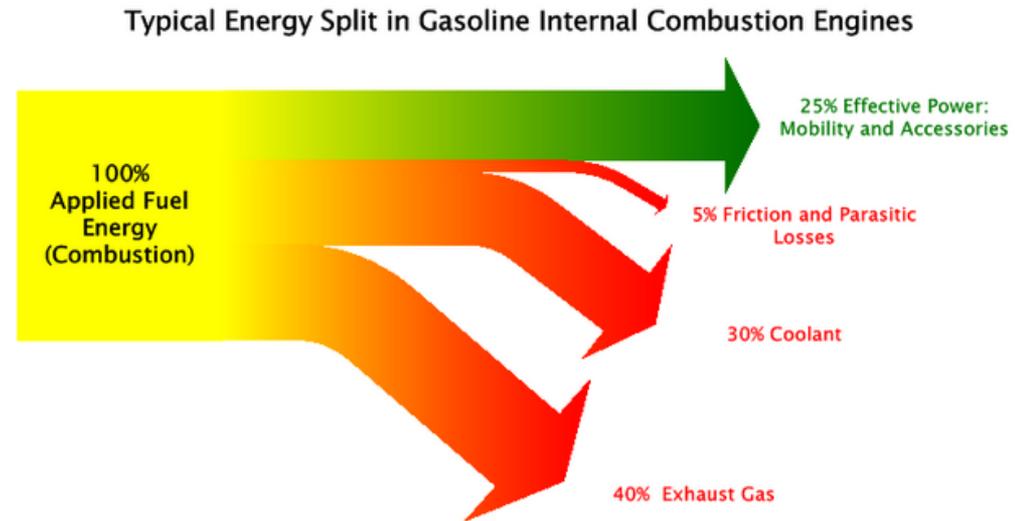
- U.S. could decrease energy needs by 20-50% by being less wasteful.
- High mileage cars
- more energy efficient building/homes.

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



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 %)			Fuel Value (kJ/g)
	C	H	O	
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

Hydrogen, the perfect fuel?



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

The problem with Hydrogen

Storage

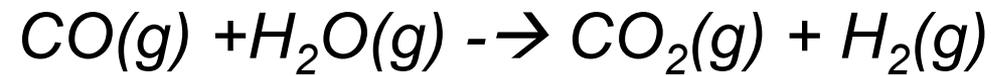
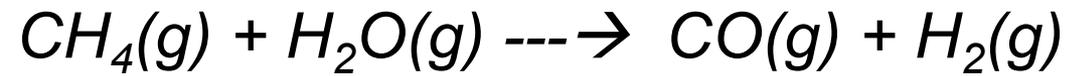
gas, less dense, hard to get enough in the car and have trunk space

Kaboom (Hindenburg)

Where do you get the hydrogen?

The problem with Hydrogen

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



Ethanol, where does it come from

- Alcoholic fermentation:
- $C_6H_{12}O_6 \rightarrow 2CO_2 + 2C_2H_5OH$ (ethanol) $\Delta H = -76$ 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) $\Delta H = -76 \text{ kJ/mol}$
- $-1270 \quad 2(-393) \quad 2(-280)$
- (anaerobic, yeast can do this, we can't) only to 10%.
- Distillation (requires energy) to purify.

Alcohol combustion:



But why would this be better for global warming?

Ethanol

- Because it comes from plants
- And plants run the reverse combustion reaction
- Us (and everything else alive on the earth):
- $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$
- Plants:
- $6CO_2 + 6H_2O + \text{light} \rightarrow C_6H_{12}O_6 + 6O_2$

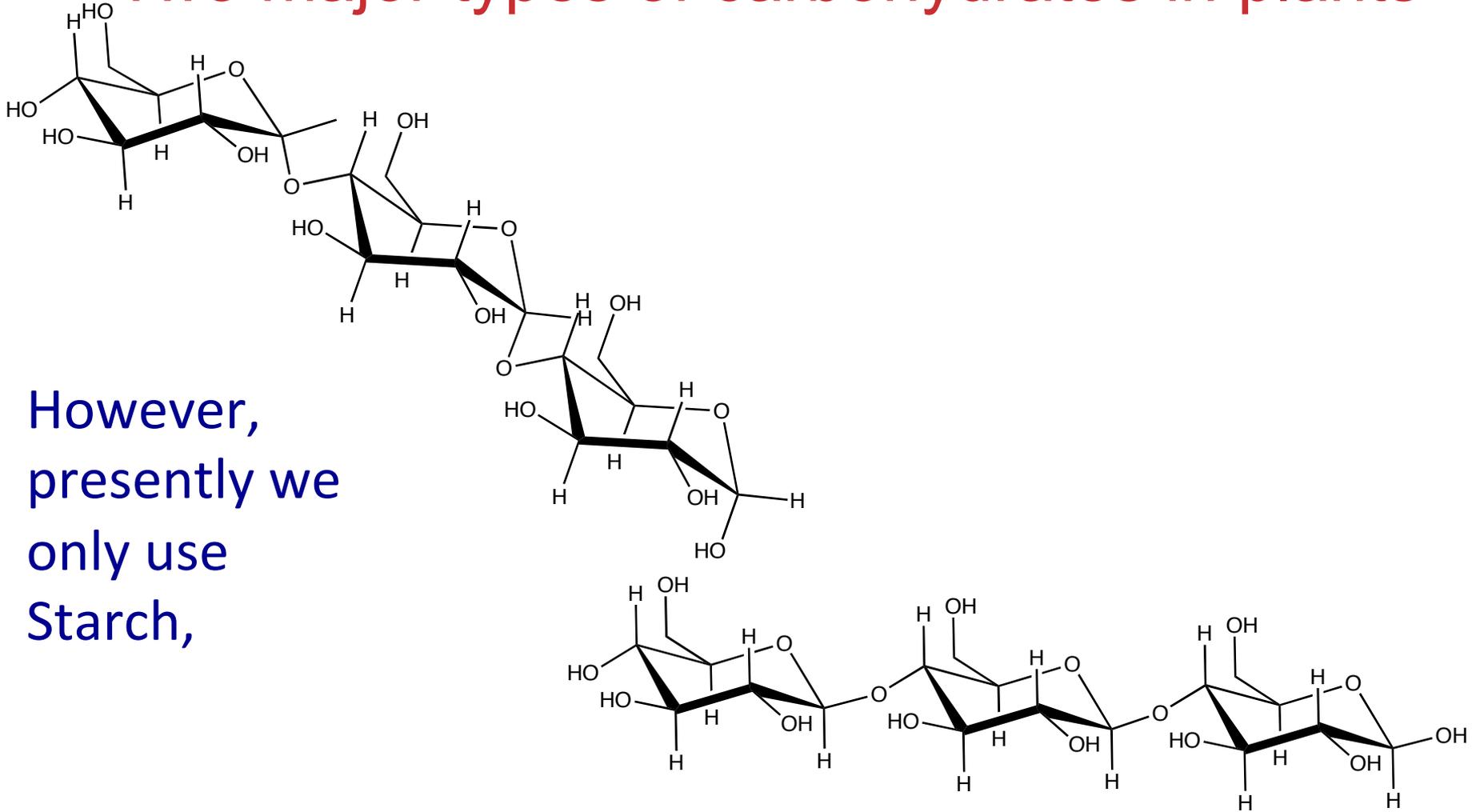
Net CO_2 production could therefore be 0.

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

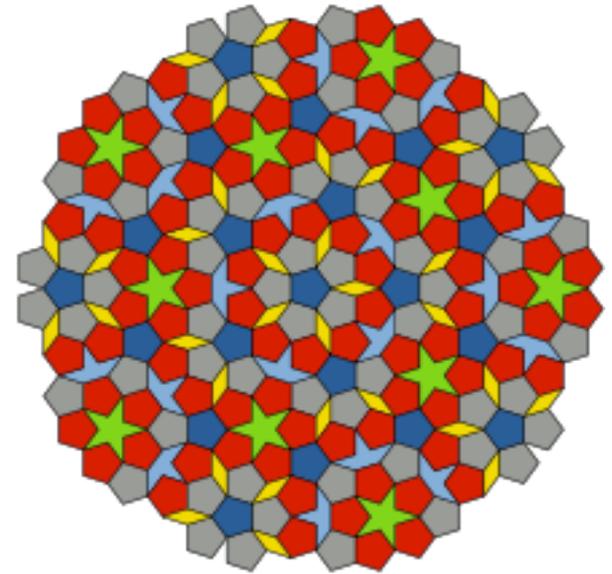
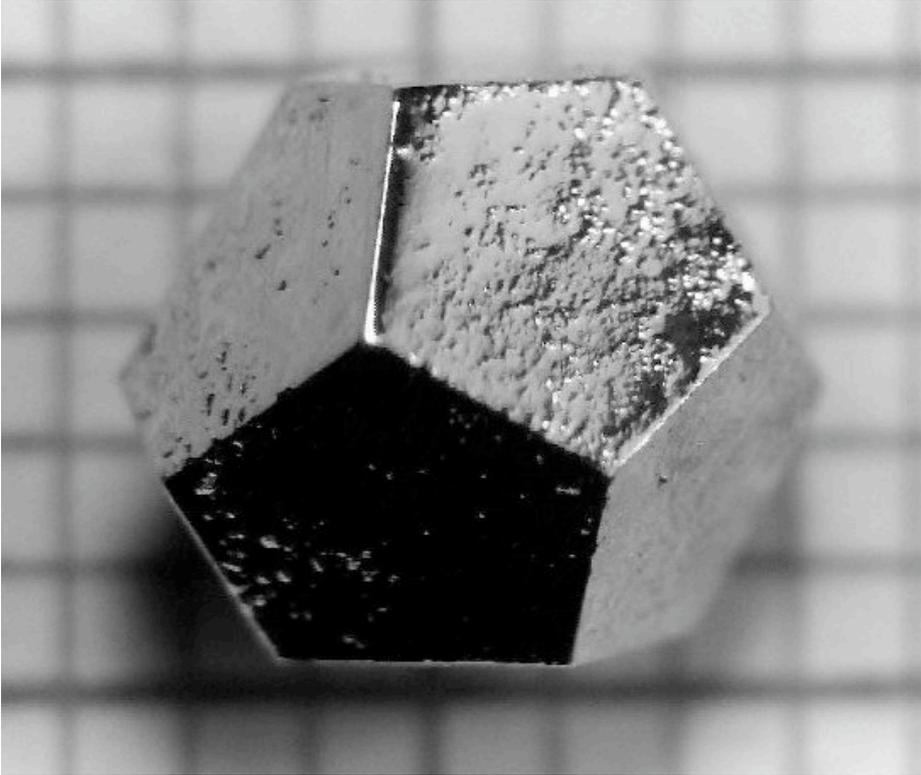
- Energy yield (how much E out versus E in)?
- Break even price (how much/gallon of gas equivalents (present corn ethanol is 2.25/gallon just to make)).
- Where is the technology NOW?
- Is storage required, & if so, how you gonna do it
- (solar when the sun doesn't shine)
- Remember, at present Batteries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

- $2\text{Al} + \text{Fe}_2\text{O}_3 \longrightarrow \text{Al}_2\text{O}_3 + 2\text{Fe}$
- What kind of reaction is this?
- Why does it happen?
- Used for welding railroad tracks
- What is the heat of reaction given:
- $2\text{Fe} + 3/2\text{O}_2 \longrightarrow \text{Fe}_2\text{O}_3 \quad \Delta H = -825.5 \text{ KJ}$
- $2\text{Al} + 3/2\text{O}_2 \longrightarrow \text{Al}_2\text{O}_3 \quad \Delta H = -1675.7 \text{ KJ}$

The Thermite Reaction

- $2\text{Al} + \text{Fe}_2\text{O}_3 \longrightarrow \text{Al}_2\text{O}_3 + 2\text{Fe}$
 - What is the heat of reaction given:
 - $2\text{Fe} + 3/2\text{O}_2 \longrightarrow \text{Fe}_2\text{O}_3 \quad \Delta H = -825.5 \text{ KJ}$
 - $2\text{Al} + 3/2\text{O}_2 \longrightarrow \text{Al}_2\text{O}_3 \quad \Delta H = -1675.7 \text{ KJ}$
 - $2\text{Al} + 3/2\text{O}_2 \longrightarrow \text{Al}_2\text{O}_3 \quad \Delta H = -1675.7 \text{ KJ}$
 - $\text{Fe}_2\text{O}_3 \longrightarrow 2\text{Fe} + 3/2\text{O}_2 \quad \Delta H = 825.5 \text{ KJ}$
-
- $2\text{Al} + \text{Fe}_2\text{O}_3 \longrightarrow \text{Al}_2\text{O}_3 + 2\text{Fe} \quad \Delta H = -850.2 \text{ KJ}$

A thermite mystery:

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