FRIDAY, OCTOBER 31, 2025 AP CHEMISTRY

CH. 5 THERMOCHEMISTRY

2. STIRLING ENGINE
- HOT WATER
- ICE W/WATER

(1.) IR THERMOMETER
TEMP = FEELING
VS. = HEAT ENERGY
(AVG. KINETIC ENERGY)

3. DRINKING BIRD
VS.
HAND BOILER (WITH ICE!)

5.1 ENERGY

IT IS THE CAPACITY TO DO WORK OR TO TRANSFER HEAT.

ENERGY IS AN ABSTRACTION OR A CONCEPT WE USE TO ORGANIZE OUR THINKING ABOUT HOW THINGS WORK. THE MAIN FEATURE OF THIS CONCEPT IS THAT THE AMOUNT OF ENERGY IS CONSTANT: IT CANNOT BE CREATED OR DESTROYED. ANOTHER WAY TO SAY THIS IS, ENERGY IN EQUALS ENERGY OUT.

THIS IS THE FIRST LAW OF THERMODYNAMICS.

ENERGY CAN BE TRANSFORMED IN A VARIETY OF WAYS — THIS IS HOW WE UNDERSTAND THE NEVER-CREATED-OR-DESTROYED IDEA. IT'S KIND OF LIKE A KID THAT KEEPS CHANGING THE RULES OF A GAME. WHENEVER ENERGY IS UNACCOUNTED FOR, WE SAY IT HAS TRANSFORMED. THESE TRANSFORMATIONS GIVE US INSIGHT INTO PHYSICAL AND CHEMICAL CHANGES.

FORMS OF ENERGY: KINETIC (MOTION), POTENTIAL, ELECTRICAL, LIGHT, HEAT, SOUND, ETC.

FOR CHEMICAL THERMODYNAMICS WE USE TWO CATEGORIES FOR ENERGY: WORK AND HEAT

VARIABLES: w FOR WORK (omega Ω ω)

q FOR HEAT

WORK

$\underline{w}$ REPRESENTS A QUANTITY OF ENERGY IN JOULES (J) OR KILOJOULES (kJ)

WORK IS A FORCE ACTING OVER A DISTANCE

$$w = F \cdot d$$

UNITS

$$J = N \cdot m$$

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

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

FOR US, WE WILL ONLY CONSIDER CHANGES IN VOL. OF A GAS AT CONSTANT PRESSURE

$w = P\Delta V$) IF IN SI UNITS THIS IS IN JOULES

(Pa)(L)

$$\left(\frac{kg\, m/s^2}{m^2}\right)(m^3) = kg\frac{m^2}{s^2} = J$$

HEAT

$\underline{q}$ REPR. A QTY. OF HEAT IN J OR kJ

FUNDAMENTALLY, HEAT IS THE KINETIC ENERGY IN A COLLECTION OF MOLECULES. IT IS A FUNCTION OF MASS AND TEMPERATURE. ($q = m\Delta T \cdot C$) (C: HEAT CAPACITY)

HEAT NATURALLY MOVES FROM OBJECTS WITH A HIGHER TEMP. TO OBJ. W/ A LOWER TEMP. BY CONDUCTION, CONVECTION, OR RADIATION.

FIRE SYRINGE DEMO!

STOPPED HERE 2025-10-31

Tu 2025-11-04 APChem

HEAT AND TEMPERATURE ARE NOT THE SAME THING!

FIRST, NOTE THAT A BATHTUB OF WATER AT 37°C HAS A LOT MORE HEAT THAN A CUP OF TEA AT 95°C. THIS IS B/C HEAT DEPENDS ON TEMP. AND ON MASS. WE'LL LOOK AT THIS MORE CLOSELY WHEN WE DISCUSS CALORIMETRY, OR THE MEASUREMENT OF HEAT.

SECOND, LET'S UNDERSTAND HEAT AT A MOLECULAR SCALE. IT HAS TWO ASPECTS:

1. THE FASTER A COLLECTION OF MOLECULES IS MOVING, THE MORE HEAT THERE IS.
2. WHEN BONDS BREAK, IT ABSORBS HEAT. WHEN BONDS FORM, IT GIVES OFF HEAT. (WE DETECT THIS BY CHANGES IN TEMP.)

DEFINING SOME IMPORTANT WORDS:

EXOTHERMIC MEANS A PROCESS WHICH GIVES OFF HEAT. SYMBILICALLY WE SHOW THIS WITH A MINUS SIGN $(-q)$ TO INDICATE HEAT IS GOING OUT OF A SYSTEM.

ENDOTHERMIC MEANS A PROCESS WHICH ABSORBS HEAT. WE SHOW THIS WITH A PLUS-SIGN $(+q)$ TO INDICATE HEAT IS ENTERING A SYSTEM.

AT THE MOLECULAR SCALE, BOND FORMATION IS EXOTHERMIC AND BREAKING BONDS IS ENDOTHERMIC.

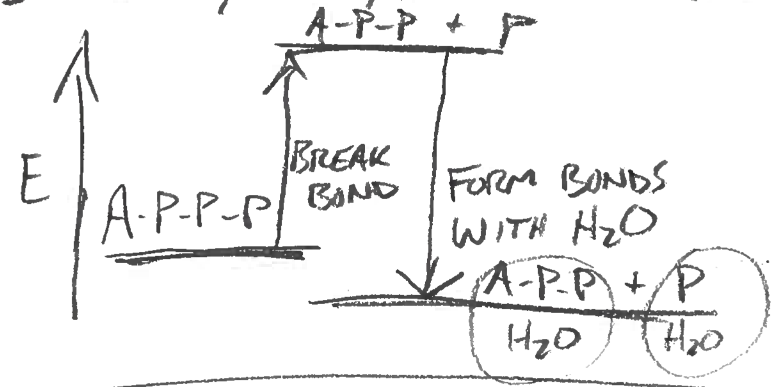
BONDS FORMING = EXOTHERMIC

BONDS BREAKING = ENDOTHERMIC (TRY SOME STRONG MAGNETS)

Do Boiling Acetone at Reduced Pressure demo

- Boiling water: constant 100°C
- Boiling acetone: temp drops from 22°C to 8.5°C
- Give students time to answer Qs, then discuss (see filled out handout)

Aside: Wait, wait, wait. What about ATP?! (ATP → ADP + P + energy)

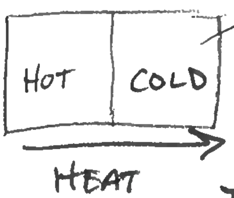


How does heat affect temperature or why is this so confusing?

1. Heat is exchanged physically
2. Bonds forming/breaking

Endothermic Change (+q)

1. A hot object in contact with a cold object.



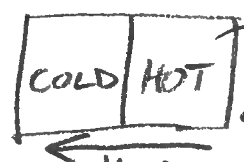
For the cold object heat enters the system. As a result, its temp. rises.

+q means $+\Delta T$ b/c $T_f > T_i$ (final) (initial)

2\. A. If a chem. or phys. change takes place so the energy of bonds broken equals energy of bonds formed then the system is at equilibrium. In this case temp. is constant.
For ex. ice melting at 0°C
water boiling at 100°C

Exothermic Change (−q)

1\.

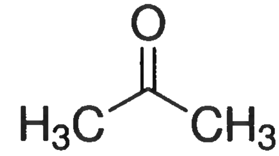


For the hot object heat leaves the system. As a result, its temp falls.

−q means $-\Delta T$ b/c $T_f < T_i$

2A. In a process that happens slowly so it can remain at equilibrium the temp. can remain constant.
For ex. water at 0°C that freezes slowly in a freezer.

Boiling Acetone at Reduced Pressure



Acetone

There are two ways to bring a liquid to a boil. First, put the liquid in a pot and set it on the stove. This works well with water to make tea or cook pasta. The added heat from the stove gives the water a high enough temperature to begin to boil and the continued addition of heat keeps the boiling going. The second way to bring a liquid to a boil does not require an input of heat at all. Simply place the liquid in a sealed container and connect the container to a vacuum pump to reduce the air pressure inside. When the pressure gets low enough, the liquid comes to a boil, no stove required.

This second way of bringing a liquid to a boil may not be familiar to most people. The kind of equipment needed for this experiment is not found in most kitchens. However, recipes and packaged foods are likely to be found in a kitchen and some of these include additional instructions for people who are cooking at high elevation. In Sante Fe, New Mexico (elev. 7,000 ft) the atmospheric pressure is about 0.8 atmospheres. At this pressure water boils at 93°C (199°F). La Paz, Bolivia (the highest capital city in the world) has an elevation of 11,980 ft (air pressure of 0.7 atm) and the boiling point of water there is 88°C (190°F). The higher you go, the lower the boiling point. This has to do with air pressure. At higher elevation, the atmospheric pressure is lower. At lower pressure, water boils at a lower temperature. Boiling is a phenomenon that depends not just on temperature but also on air pressure. In order for bubbles of vapor (molecules of the liquid in the gas phase) to form inside the liquid the gas pressure inside the bubbles must equal the external pressure. If the external pressure is higher then bubbles can't form until the liquid is at a higher temperature. If the external pressure is lower then bubbles will form when the liquid is at a lower temperature. Water can even boil at room temperature if the pressure is low enough. At 17.5 torr (0.0231 atm) water boils at 20°C, which is room temperature.

In order to really understand what's going on when a liquid boils a good understanding of heat and temperature is required. Molecules and atoms are in constant, random motion. Temperature is a measure of the average kinetic energy of molecules, their energy of motion. At low temperature molecules have a lower average kinetic energy, which means they have a lower average speed. If no phase changes or chemical reactions are going on then when heat is added to a material, its molecules will begin to move faster. Although the molecules are too small to see, it is possible to measure the temperature and the temperature rises as heat is added. There is heat in everything that has a temperature above absolute zero. For example, when an object with a higher temperature is placed in contact with an object with a lower temperature heat moves from the higher-temperature object to the lower-temperature object. In order to have heat, it is not necessary to burn some fuel or turn on a stove.

Although all changes in temperature involve heat moving into or out of a substance, not all transfers of heat cause the temperature to change. For example, when the water in the pot on the stove is boiling it has a constant temperature of 100°C (212°F) despite the fact that the burner underneath it is hundreds of degrees hotter. The burner provides heat to the water in the pot but the temperature of the water does not rise. Why should this be? The temperature of boiling water is constant because the heat that is added to the water is consumed in driving the phase change from liquid to gas. Instead of raising the temperature of the water, the heat breaks the bonds holding one water molecule in contact with its neighbors. All molecules experience a certain amount of stickiness (or intermolecular forces of attraction). This stickiness requires energy to overcome. Just as it takes a small effort to pull two magnets apart when they are stuck together, it takes a small amount of heat energy to pull two water molecules apart. The heat provided by the stove breaks the bonds holding water molecules together and these molecules then escape in the vapor phase, taking their additional energy with them. Heat not only gets used up breaking bonds but the energy is also carried away by the hot steam. Boiling, and melting, too, for that matter, require heat and consume it without allowing the heat to raise the temperature.

When sufficient heat is added to a boiling liquid its temperature remains constant. This raises an interesting question: when a liquid boils because of reduced pressure, what happens to its temperature? In the demonstration air pressure is reduced in a flask containing acetone. The acetone comes to a boil due to the reduced pressure but no external heat source is supplied. The temperature of the acetone drops—it drops further the longer it boils. Boiling requires heat and the heat has to come from somewhere. In this case, the heat is coming from the acetone itself. As the heat in its own molecules is used up in the transition from the liquid to the vapor state the temperature drops. In order for a molecule to escape into the vapor phase it must move fast enough to break the bonds to its neighbors. If the neighbors shove it hard enough then a molecule can join up with others in the vapor phase and make a bubble. But the neighbors of the now-escaped molecule gave up some of their kinetic energy when they shoved it away. A lower kinetic energy means they are moving more slowly. When molecules move more slowly we can detect that as a drop in temperature. In a way, this is like Dorothy in the Wizard of Oz. She had the ruby slippers on the entire time and could have gone home at any moment. The flask of acetone has the heat that it needs to boil within its own molecular motions. Acetone can be made to boil at 20°C with a pressure of 108 torr (0.141 atm). The normal boiling point of acetone (at 1 atm) is 56.5°C. As the acetone boils, its temperature can be reduced to about 10°C.

GROUP X

Questions

1. Endothermic changes consume heat energy. Exothermic changes give off heat energy. Classify the phase changes below as endothermic or exothermic. For each one, write one sentence that justifies your answer. Consider the formation or breaking of bonds between molecules in your answer.
   a. solid to liquid ENDO B/C BONDS BREAK
   b. liquid to gas " " "
   c. gas to liquid EXO B/C BONDS FORM
   d. liquid to solid EXO " " " "

2. When water is boiled on a stove the temperature remains constant at around 100°C. This is despite the fact that the electric burner is constantly adding heat to the water. Why does the temperature remain constant?
   1. HEAT IS USED UP BREAKING BONDS
   2. HEAT LEAVES WITH THE EVAPORATED MOLECULES

3. What happened in the demonstration when the flask of acetone was hooked up to the aspirator and its internal pressure was reduced? List all relevant observations.
   IT BOILED AND ITS TEMP. DROPPED.

4. When the temperature of a system drops during a physical or chemical change is heat being consumed or produced? Explain.
   IT IS BEING CONSUMED — AS HEAT IS CONSUMED IN BREAKING BONDS MOLECULES SLOW DOWN SO WE ~~see~~ A DECREASE IN TEMP.

5. Prior to seeing this demonstration, what would you have said about boiling about whether it was exothermic or endothermic? Why? Have you changed your mind? Explain.
   PROBS. EXOTHERMIC B/C HOT.
   YES — MR K SAID SO.

6. Heat is a form of energy and energy cannot be created or destroyed. Where does heat energy go when it enters a system and the system's temperature stays constant or when it drops?
   1. IT BREAKS BONDS (IT BECOMES POTENTIAL ENERGY)
   2. IT GOES INTO THE EVAPORATING MOLECULES

7. Does freezing water give off heat or consume it? Justify your answer in terms of molecular motion.
   IT GIVES OFF HEAT AS BONDS FORM.

This demonstration is based on demonstration 1.1 on pg. 5 of <u>Chemical Demonstrations, Vol. 1</u> by Bassam Z. Shakhashiri.
I made a video of this demonstration a few years ago. View it here: https://youtu.be/BxB2uVtL4rU.

8. WHERE DID THE HEAT COME FROM THAT MADE THE ACETONE CHANGE PHASE? FROM ITS OWN INTERNAL HEAT!

4a

(ENDOTHERMIC)

2.B. A CHEM. OR PHYS. CHANGE TAKES PLACE IN WAY THAT THE ENERGY OF BONDS BROKEN IS GREATER THAN THE ENERGY OF BONDS FORMED: IN THIS CASE FOR $+q$ TEMP GOES DOWN.

HEAT GOES IN — TEMP GOES DOWN

$+q$ MEANS $-\Delta T$ B/C $T_f < T_i$

FOR EX. BOIL A LIQUID AT REDUCED PRESSURE WITHOUT A HEAT SOURCE.

Tu 2025-11-04 AP CHEM

2.B. (EXOTHERMIC)

IF ENERGY OF BONDS FORMED IS GREATER THAN ENERGY OF BONDS BROKEN THEN FOR $-q$ TEMP. RISES.

$-q$ MEANS $+\Delta T$ B/C $T_f > T_i$

FOR EX. BURN A FUEL OR CONDENSE WATER VAPOR

(HAND OUT CALOR. LAB, PRE-LAB DUE (X) M 11/10 OR Th 11/13 (Y))

STOP HERE GROUP X Tu 2025-11-04 AND GROUP Y

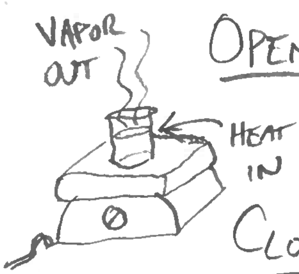
Th 2025-11-06 AP CHEM

SOME KEY TERMS:

SYSTEM: WHATEVER MATERIALS WE ARE PAYING ATTENTION TO

SURROUNDINGS: OTHER NEARBY MATERIALS

TYPES OF SYSTEMS:



OPEN SYSTEMS CAN EXCHANGE MATTER AND ENERGY WITH THE SURROUNDINGS FOR EX, WATER IN A BEAKER ON A HOT PLATE

CLOSED SYSTEMS CAN EXCHANGE ENERGY WITH THE SURR. BUT NOT MATTER, FOR EX. A PRESSURE COOKER.

ISOLATED SYSTEMS DO NOT EXCHANGE ENERGY OR MATTER WITH THE SURR., FOR EX A THERMOS OR "STANLEY" OR AN INSULATED CALORIMETER.

SOMETIMES IT'S THE PARTS OF A SYSTEM THAT INTERACT TO EXCHANGE ENERGY. FOR EX, WHEN YOU DISSOLVE NaOH IN WATER IT RELEASES HEAT. THE HEAT IS ABSORBED BY THE WATER. THIS CAN BE DONE IN A WAY THAT ALLOWS YOU TO MEASURE THE HEAT IF THE SYSTEM IS ISOLATED.

5.2 THE FIRST LAW OF THERMODYNAMICS

THREE WAYS TO STATE IT:

1. THE ENERGY CONTENT OF *The Universe* IS CONSTANT.
2. THE CHANGE IN THE INTERNAL ENERGY OF A SYSTEM EQUALS THE SUM OF HEAT AND WORK INVOLVED.

   $$\Delta E = q + w$$ ✶

3. THE HEAT LOST BY A PROCESS OR OBJECT IS GAINED BY SOMETHING NEARBY:

   ✶ $q_{sys} + q_{surr} = 0$ (A HOT OBJECT COOLS)

   $q_{rxn} + q_{H_2O} = 0$ (A CHEM. RXN. HEATS ITS SOLVENT)

   CALORIMETRY

BOTH ARE IMPORTANT FOR DOING CALCULATIONS & SOLVING PROBS.

INTERNAL ENERGY (E)

E IS THE SUM OF KINETIC AND POTENTIAL ENERGY IN A SYSTEM.

KINETIC ENERGY IS JUST THE MOTION OF MOLECULES.
POTENTIAL ENERGY DEPENDS ON CONTEXT. $PE = mgh$ h = HEIGHT
DO YOU MEAS. h FROM THE FLOOR? THE TABLETOP?
CONSIDER GASOLINE— LOTS OF PE IF BURN IT WHERE THERE'S PLENTY OF OXYGEN. NOT SO MUCH ON THE MOON, UNESS YOU BRING O_2 ALONG.
FOR THIS REASON E CAN'T BE GIVEN AN ABSOLUTE VALUE.
INSTEAD, WE MEASURE <u>CHANGES</u> TO INTERNAL ENERGY

$$\left(\Delta E = E_f - E_i\right) \qquad \Delta E = q + w$$

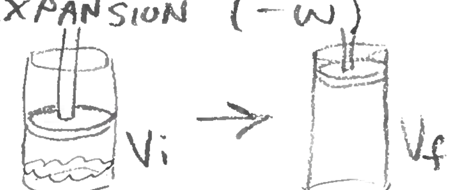
(E_f = FINAL − E_i = INITIAL)

WE CAN'T MEAS. E_f OR E_i BUT WE CAN MEAS. $q + w$.

FOR THIS LESSON AND FOR CHEMISTRY GENERALLY, WE ONLY CONSIDER ONE KIND OF WORK: THE EXPANSION OR CONTRACTION OF A GAS.
FOR EXPANSION WORK IS NEGATIVE B/C THE SYSTEM DOES WORK ON THE SURROUNDINGS AND LOSES ENERGY.
FOR CONTRACTION, WORK IS POSITIVE B/C THE SURR. DO WORK ON THE SYSTEM SO IT GAINS ENERGY.

STOPPED HERE Th 2025-11-06 GROUP X

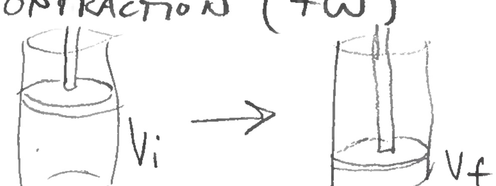
EXPANSION $(-w)$



A LIQUID EVAPORATES

$\Delta V = V_f - V_i \Rightarrow +\Delta V$

CONTRACTION $(+w)$



A VAPOR CONDENSES

$\Delta V = V_f - V_i \Rightarrow -\Delta V$

$-w$ GOES WITH $+\Delta V$
$+w$ GOES WITH $-\Delta V$

SO OUR FORMULA TO CALC. THE AMOUNT OF WORK ~~TAKES~~ USES ΔV AND THE PRESSURE DOING OR RESISTING THE WORK (P).

$$w = P\Delta V$$

FOR $+\Delta V$, w IS $+w$
FOR $-\Delta V$, w IS $-w$

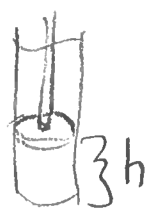
THIS IS THE OPPOSITE OF WHAT WE WANT

SI UNITS: $\frac{N}{m^2} \cdot m^3 = N \cdot m = J$

SO WE JUST THROW IN A MINUS SIGN.

$$w = -P\Delta V$$

DERIVATION: $P = \frac{F}{A}$ so $F = P \cdot A$



$\Delta h(F = P \cdot A)$

$F \cdot \Delta h = P \cdot A \cdot \Delta h$

$F \cdot d = P \cdot \Delta V$

$w = P\Delta V$

IF ΔE IS POSITIVE THEN $q + w$ IS POSITIVE
(EVEN IF ONE OF THEM IS NEGATIVE, AS LONG AS THE OTHER IS BIGGER)

IF ΔE IS NEGATIVE...

WE WILL OFTEN ASK YOU ABOUT WHETHER ΔE, q, AND w ARE POS. OR NEG.
POSITIVE MEANS THE SYSTEM GAINED ENERGY.
NEGATIVE MEANS THE SYSTEM LOST ENERGY

$+\Delta E$, $-\Delta E$
$+w$, $-w$

$+q$ ENDOTHERMIC
$-q$ EXOTHERMIC

THERE ARE NO SPECIAL WORDS FOR THESE

5.5 CALORIMETRY

THE MEASUREMENT OF THE TRANSFER OF HEAT BY MONITORING CHANGES IN TEMP.

HEAT DEPENDS ON
1. THE CHANGE IN TEMP
2. THE MASS OF THE MATERIAL
3. THE HEAT CAPACITY OF THE MATERIAL AKA THE SPECIFIC HEAT

SPECIFIC HEAT IS THE AMOUNT OF ENERGY NEEDED TO RAISE T BY 1°C/1K FOR 1 g OF THE MATERIAL.

C OR C_s UNITS: $\frac{J}{g\,°C}$ OR $\frac{J}{g\,K}$

K AND °C ARE INTERCHANGEABLE B/C ΔT IN K EQUALS ΔT IN °C

(C_m = MOLAR HEAT CAPACITY J/mol°C OR J/mol K

K | °C
373K | 100°C
ΔT = 100K | ΔT = 100°C
273K | 0°C

✱ DO NOT ADD 273 TO ΔT VALUES! OR SUBTRACT

FOR EX. $\Delta T = 298 - 273K = +25K$

$\Delta T = 25 - 0°C = +25°C$ NOT 298!

$\Delta T = T_f - T_i$

KEY EQUATIONS FOR CALORIMETRY (1[ST] LAW OF THERMO.)

$q_1 + q_2 = \emptyset$ (HEAT LOST BY OBJECT 1) + (HEAT GAINED BY OBJECT 2) = ∅

q CAN BE:
1. A NUMBER. AN AMT. OF HEAT MADE OR CONSUMED BY A CHEM. RXN.
2. $q = mC\Delta T$ AS, FOR EX., THE WATER IN WHICH A RXN TAKES PLACE

DEMO: SUPERHEATED STEAM B/C HEAT CAPACITY!

Th 2025-11-06 AP CHEM

STATE FUNCTIONS

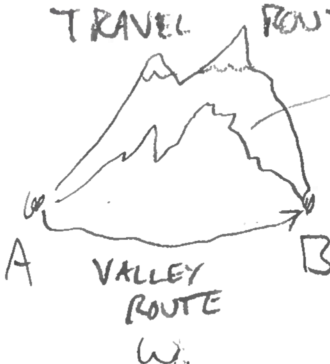
A STATE FUNCTION IS A VARIABLE WHOSE VALUE DEPENDS ONLY ON THE CURRENT STATUS. IN OTHER WORDS, THE VALUE DOESN'T DEPEND ON THE HISTORY OF THE SYSTEM. IT'S LIKE A BANK BALANCE.

STATE FUNCTIONS YOU KNOW: P V T n
m POSITION (x, y, z)

NEW STATE FUNCTIONS: ΔE (INTERNAL ENERGY) ΔH (ENTHALPY)

q AND w ARE NOT STATE FUNCTIONS

THEY ARE SIMILAR TO THE ENERGY FOR DIFFERENT TRAVEL ROUTES BTWN TWO FIXED POINTS.



$w_2 > w_1$ EVEN THOUGH YOU END UP IN THE SAME PLACE.

STOPPED HERE M 2025-11-10 GROUP X

5.3 ENTHALPY

HEAT (q) IS NOT A STATE FUNCTION. IT TURNS OUT, THOUGH, THAT HEAT AT CONSTANT PRESSURE <u>IS</u> A STATE FUNCTION. HEAT AT CONSTANT PRESSURE (q_p) IS CALLED ENTHALPY (H)

DEFINITION OF ENTHALPY: $\Delta H = \Delta E + P\Delta V$

THIS COMES FROM $\Delta E = q_p + w$ AND $w = -P\Delta V$

$\Delta E = q_p + (-P\Delta V)$ SO $q_p = \boxed{\Delta H = \Delta E + P\Delta V}$

5.4 ENTHALPIES OF RXN $\Delta H_{RXN} = H_f - H_i$

A CHEMICAL EQN WHICH INCL. A VALUE FOR ΔH_{RXN} IS CALLED A THERMOCHEMICAL EQN. THE QUANTITY, ΔH_{RXN}, IS PROPORTIONAL TO THE MOLES OF REACTANTS AND PRODUCTS IN A BALANCED CHEMICAL EQUATION.

FOR EX $2H_{2(g)} + O_{2(g)} \rightarrow 2H_2O_{(g)}$ $\Delta H = -483.6\,kJ$

PHASE OF MATTER, MATTERS!

STOPPED HERE GROUP Y Th 2025-11-06

RULES FOR THERMOCHEMICAL EQUATIONS

① ENTHALPY IS AN EXTENSIVE PROPERTY. THAT IS, THE AMOUNT OF HEAT RELEASED/ABSORBED DEPENDS ON THE AMOUNTS OF REACTANTS/PRODUCTS.

FOR EX. $0.5\,mol\,O_2 \cdot \frac{-483.6\,kJ}{1\,mol\,O_2} = \boxed{-241.8\,kJ}$

② THE ~~same~~ CHEM. EQN. WRITTEN IN REVERSE HAS THE SAME ABSOLUTE VALUE FOR ΔH, BUT THE OPPOSITE SIGN. (AKA, THE MAGNITUDE OF ΔH)

FOR EX. $2H_2O_{(g)} \rightarrow 2H_{2(g)} + O_{2(g)}$ $\boxed{\Delta H = +483.6\,kJ}$

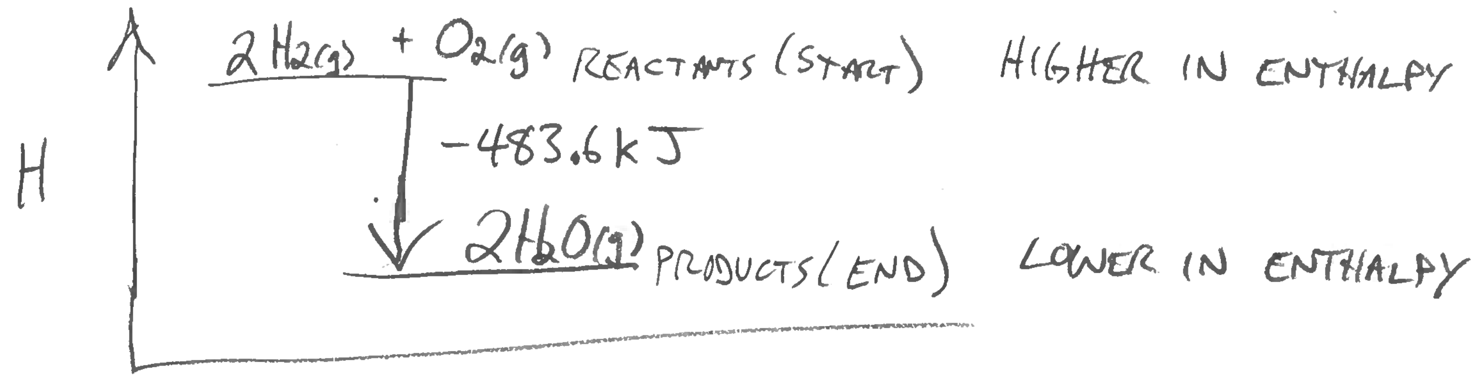
③ CHANGING THE STATE OF MATTER WILL CHANGE THE VALUE OF ΔH_{RXN}.

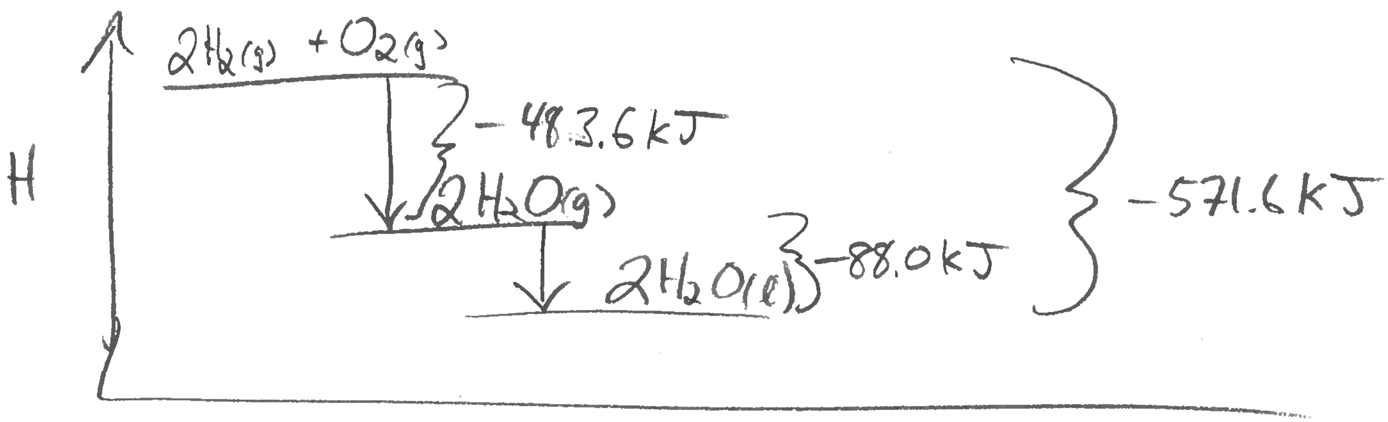
FOR EX. $H_2O_{(g)} \rightarrow H_2O_{(l)}$ $\Delta H = -44\,kJ$

SO $2H_{2(g)} + O_{2(g)} \rightarrow 2H_2O_{(l)}$ $\Delta H = -483.6\,kJ + 2(-44.0\,kJ)$

$\boxed{-571.6\,kJ}$

ENTHALPY DIAGRAMS





CONFIRMING WHAT MAY ALREADY BE CLEAR:

$+\Delta H$ MEANS ENDOTHERMIC

$-\Delta H$ MEANS EXOTHERMIC (JUST LIKE q)

5.6 HESS'S LAW

BECAUSE ΔH IS A STATE FUNCTION ITS VALUE IS INDEPENDENT OF THE RXN PATHWAY. WHETHER YOU EAT A PIECE OF CHOCOLATE OR BURN IT UP IN A CALORIMETER, THE SAME AMOUNT OF HEAT IS RELEASED.

SOMETIMES, IT'S INCONVENIENT OR IMPOSSIBLE TO DIRECTLY MEASURE ΔH_{RXN} FOR A RXN WE WANT TO STUDY. HESS'S LAW IS JUST THE IDEA THAT YOU ADD CHEM. EQN.S TOGETHER TO MAKE A SPECIFIC RXN. AND THAT WHEN YOU DO SO, YOU CAN ADD UP ΔH VALUES.

ΔH°_{RXN} IS THE SYMBOL WE USE FOR THE ENTHALPY OF RXN UNDER STANDARD CONDITIONS.

(STANDARD → LITTLE CIRCLE)

FOR THERMOCHEMISTRY STD. PRESSURE IS 1 atm

STD. TEMP. IS 25°C (298 K)

STD. CONC. IS 1.0 M (1 mol/L)

HERE IS HOW TO CALC. ΔH°_{RXN} FOR SOME EQN. OF INTEREST USING KNOWN VALUES:

FOR EX. CALC. ΔH°_{RXN} FOR $2C_{(s)} + H_{2(g)} \rightarrow C_2H_{2(g)}$

GIVEN:

① $C_2H_{2(g)} + \frac{5}{2}O_{2(g)} \rightarrow 2CO_{2(g)} + H_2O_{(l)}$ $\Delta H_1^\circ = -1299.6\text{ kJ}$

② $C_{(s)} + O_{2(g)} \rightarrow CO_{2(g)}$ $\Delta H_2^\circ = -393.5\text{ kJ}$

③ $H_{2(g)} + \frac{1}{2}O_{2(g)} \rightarrow H_2O_{(l)}$ $\Delta H_3^\circ = -285.8\text{ kJ}$

TAKE RXN ② TIMES 2:

$$2C + 2O_2 \rightarrow 2CO_2 \quad \Delta H = 2\Delta H_2 = 2(-393.5\text{ kJ})$$

TAKE RXN ③ AS WRITTEN $\Delta H = \Delta H_3 = -285.8\text{ kJ}$

TAKE RXN ① IN REVERSE (SO, TIMES −1)

$$2CO_{2(g)} + H_2O_{(l)} \rightarrow C_2H_{2(g)} + \frac{5}{2}O_{2(g)} \quad \Delta H = -\Delta H_1 = +1299.6\text{ kJ}$$

ADD THEM UP!

$$2C + \cancel{2O_2} + H_2 + \cancel{\tfrac{1}{2}O_2} + \cancel{2CO_2} + \cancel{H_2O} \rightarrow \cancel{2CO_2} + \cancel{H_2O} + C_2H_2 + \cancel{\tfrac{5}{2}O_2}$$

($2O_2 + \frac{1}{2}O_2 = \cancel{\frac{5}{2}O_2}$)

$$2C + H_2 \rightarrow C_2H_2$$

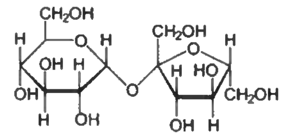
STOPPED HERE GROUP Y M 2025-11-10

$$\Delta H^\circ_{RXN} = 2(-393.5) + (-285.8) + (+1299.6) = \boxed{+226.8\text{ kJ}}$$

↳ DO CARBON SOUFFLÉ DEMO (DO NOT EAT)

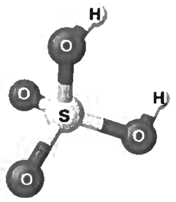
Student Worksheet for the Demonstration Exothermic Dehydration of Sugar

Table sugar is a carbohydrate known by the scientific name sucrose. Its formula is $C_{12}H_{22}O_{11}$. It is a disaccharide made of linked molecules of glucose and fructose. A disaccharide is a carbohydrate with two linked sugar molecules. Starches are composed of many linked sugar molecules and are known as polysaccharides.



sucrose molecule

Carbohydrates are so named because their empirical formulas may be written as a combination of carbon and whole number multiples of molecules of water. Sucrose for example can have its formula re-written as $C_{12}(H_2O)_{11}$.



Sulfuric Acid

Concentrated sulfuric acid is 98% pure H_2SO_4 by mass. Its concentration may be expressed as 18 mol/L. Sulfuric acid is the chemical manufactured in the largest amount worldwide. Annual production is likely near 160 million tons. It is mainly used to dissolve ores in mining and phosphate rock in the manufacture of fertilizers. Because it is a diprotic acid (meaning it has two hydrogen ions, or protons, per molecule) sulfuric acid provides the equivalent of 36 mol/L for the concentration of H^+. This is 45 times the H^+ concentration of 5% table vinegar. Besides being an acid, H_2SO_4 is also a powerful dehydrating agent due to its highly exothermic enthalpy of solution.

The heat of reaction in this demonstration may be calculated by a Hess's Law combination of reactions:

Combustion of Sucrose $C_{12}H_{22}O_{11} + 12O_2 \rightarrow 12CO_2 + 11H_2O \quad \Delta H = -5641$ kJ

Combustion of Pure C $C + O_2 \rightarrow CO_2 \quad \Delta H = -393.5$ kJ

Questions

1. Use Hess's Law to combine the reactions given above to produce a reaction in which sucrose is converted completely into elemental carbon and water. **(a)** Write the resulting balanced chemical equation. **(b)** What is the overall change in enthalpy (ΔH)?

$C_{12}H_{22}O_{11} + 12O_2 \rightarrow 12CO_2 + 11H_2O \quad -5641$ kJ

$12(CO_2 \rightarrow C + O_2) \quad + 12(+393.5$ kJ$)$

$C_{12}H_{22}O_{11} \rightarrow 12C + 11H_2O \quad -919$ kJ/mol sucrose

2. Forty grams of sucrose are used in the demonstration. How much heat does the process of converting sugar into carbon and water produce in this demonstration?

$40g\ C_{12}H_{22}O_{11} \cdot \frac{1\ mol}{342g} \cdot \frac{-919\ kJ}{1\ mol\ C_{12}H_{22}O_{11}} = -107$ kJ

3. Consider the following physical process and its accompanying change in enthalpy:
$H_2SO_4(l) \rightarrow H_2SO_4(aq) \quad \Delta H = -41$ kJ
This equation shows the hydration of sulfuric acid. When sulfuric acid dissolves in water a large quantity of heat is released. This is why chemists are told 'do as you oughta, add acid to watah'. When you add the

13a

dense acid to water it sinks to the bottom and any boiling of the water that may occur does not lead to spattering hot acid all over the chemist. In this demonstration your teacher poured about 40 mL of 98% sulfuric acid into the sugar. How much heat is released when this much sulfuric acid is diluted with water? The density of 98% sulfuric acid is 1.84 g/mL.

$$40\,mL \cdot \frac{1.84\,g}{1\,mL} \cdot \frac{98\,g\ H_2SO_4}{100\,g\ SOLN} \cdot \frac{1\,mol}{98\,g} \cdot \frac{-41\,kJ}{1\,mol} = -30.2\,kJ$$

4. Combining your calculations so far, how much heat is ~~released in the classroom~~ demonstration you witnessed?

$$-107 + (-30.2) = -137.2\,kJ$$

5. Water has an enthalpy of vaporization ~~of~~ +40.7 kJ/mol. Given the amount of water produced in the overall chemical change in the ~~demonstration~~ determine whether enough heat has been released in order to vaporize all of the water. Prove your answer with a calculation and if it was not enough heat then calculate what amount of water actually can be vaporized by the heat released during the demonstration.

SHOULD BE +44 kJ!

$$40\,g\ C_{12}H_{22}O_{11} \cdot \frac{1\,mol}{342\,g} \cdot \frac{11\ H_2O}{1\ C_{12}H_{22}O_{11}} \cdot \frac{+40.7\,kJ}{1\,mol} = +52.3\,kJ$$

$$-137.2 + (+52.3) = -84.7\,kJ$$

84.7 kJ OF HEAT IS RELEASED AFTER ACCOUNTING FOR → VAPORIZING H_2O

6. This demonstration is known as the 'carbon soufflé'. Using your best writing, ~~and referencing the relevant~~ scientific details, write a description of what happens in the demonstration. Explain what you saw using what you know about thermochemistry. Also, explain why it has been given a nickname referring to a food preparation.

In case you missed the classroom demonstration there is a video I made which you can watch: https://youtu.be/xV3d94FrjzE. This demonstration is based on demonstration 1.32 on pg. 77 of Chemical Demonstrations, Vol. 1 by Bassam Z. Shakhashiri.

HOW MUCH BAKING SODA DO I NEED?

$$2NaHCO_3 + H_2SO_4 \rightarrow 2H_2O + 2CO_2 + Na_2SO_4$$

Na^+ HCO_3^- ; $2H^+ + SO_4^{2-}$

$$40\,mL \cdot \frac{1.84\,g}{1\,mL} \cdot \frac{1\,mol}{98\,g} \cdot \frac{2\,NaHCO_3}{1\,H_2SO_4} \cdot \frac{84\,g}{1\,mol} = 126\,g\ NaHCO_3$$

13/6

5.7 ENTHALPIES OF FORMATION

ΔH_f° = STD. ENTHALPY OF FORMATION

THIS IS THE ΔH°_{RXN} FOR THE FORMATION OF <u>ONE MOLE</u> OF A SUBSTANCE FROM ITS ELEMENTS UNDER STANDARD CONDITIONS.

(1 atm 298K FOR SOLNS, 1 M)

YOU CAN LOOK UP ΔH_f° VALUES IN APPENDIX C.

THE NUMBERS IN APP. C UNDER ΔH_f° REFER TO A RXN THAT YOU CAN WRITE, FOR EX, AS FOLLOWS:

$$C_{(s)} + O_{2(g)} \rightarrow 1CO_{2(g)} \quad \Delta H_f^\circ = -393.5\,kJ$$

(NOT DIAMOND)

$$2Al_{(s)} + \frac{3}{2}O_{2(g)} \rightarrow 1Al_2O_{3(s)} \quad \Delta H_f^\circ = -3350\,kJ$$

THE ΔH_f° FOR PURE ELEMENTS IS ZERO! (BY DEFINITION)

$$O_{2(g)} \rightarrow O_{2(g)} \quad \Delta H_f^\circ = \emptyset\,kJ$$

WE USE ΔH_f° VALUES TO CALC. ΔH_{rxn}° FOR ANY ARBITRARY CHEMICAL EQUATION.

(THE SUM OF ΔH_f° FOR PRODUCTS MULT. BY STOICH. COEFF.) − (THE SUM OF ΔH_f° FOR REACTANTS MULT. BY STOICH. COEFF.)

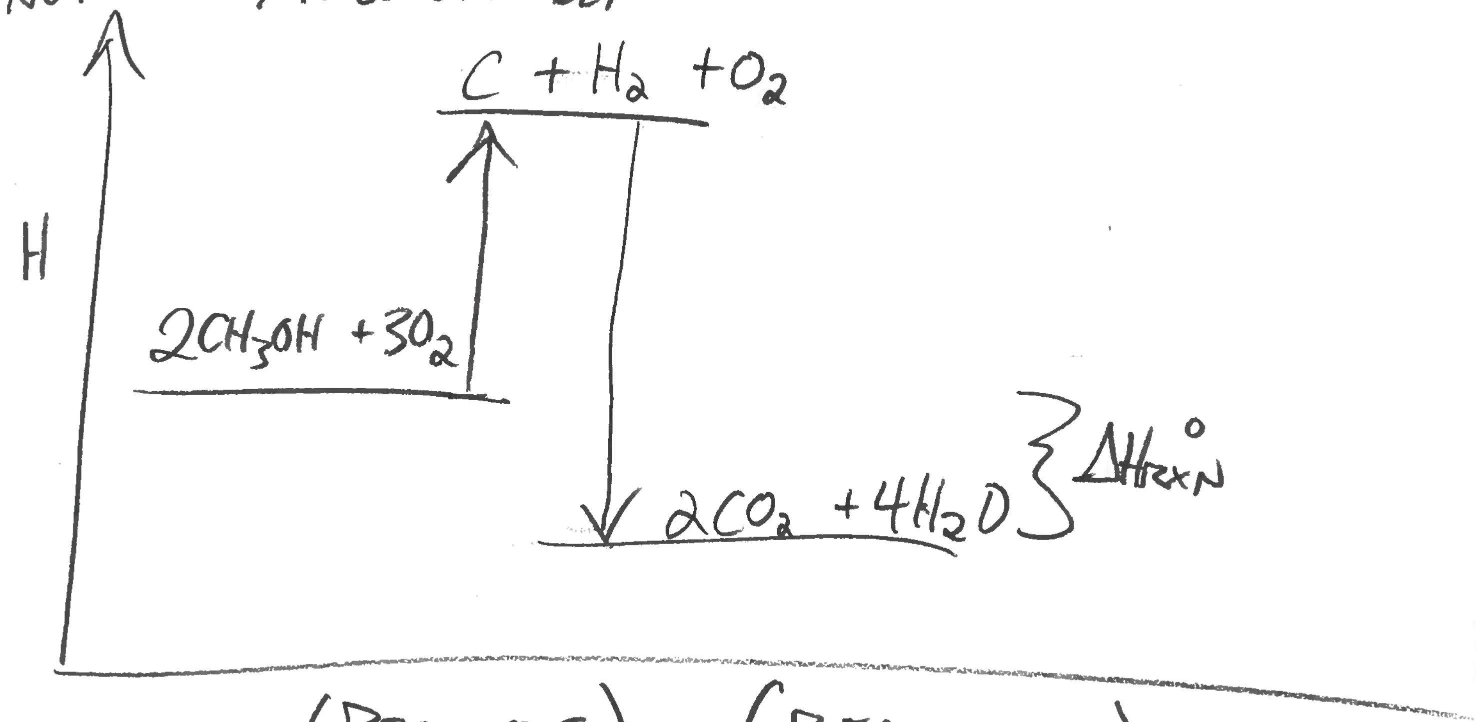
$$\Delta H^\circ_{RXN} = \sum n \Delta H^\circ_{f\,(PRODUCTS)} - \sum m \Delta H^\circ_{f\,(REACTANTS)}$$

↑ SIGMA = SUM; ↑ COEFF.

FOR EX. CALC. ΔH°_{RXN} USING ΔH_f° VALUES FOR

$$2CH_3OH_{(g)} + 3O_{2(g)} \rightarrow 2CO_{2(g)} + 4H_2O_{(g)}$$

NOTIONALLY/THEORETICALLY:



(PRODUCTS) − (REACTANTS)

$$\left[2(\underset{CO_2}{-393.5\text{ kJ}}) + 4(\underset{H_2O}{-283.85\text{ kJ}})\right] - \left[2(\underset{CH_3OH}{-201.2\text{ kJ}}) + 3(\underset{O_2}{\emptyset})\right]$$

$$\boxed{\Delta H^\circ_{RXN} = -1520\text{ kJ}}$$

MONDAY, NOVEMBER 10, 2025 AP CHEMISTRY

CALORIMETRY LAB

SCIENTIFIC MEASUREMENTS

1. HEAT CAPACITY OF A METAL OR METALS
2. ENTHALPY OF SOLUTION FOR KNO_3

SCIENTIFIC SKILLS

1. READING A THERMOMETER :)
2. CALCULATING CALORIMETRIC RESULTS

RE: READING A THERMOMETER:

- EST. TO THE NEAREST TENTH OF A DEGREE
- ALWAYS USE THE SAME ONE — AND REMEMBER IT ALSO HAS A TEMP.

$= 21.2°C$

$q = mC\Delta T$

$q_1 + q_2 = 0$

PRE-LAB QUESTIONS

3, 5, 7, 8, 9

(3) a. BOILING WATER: ENDO.

b. COOLING PERSPIRATION: ENDO.

c. CONDENSING WATER: EXO.

d. FREEZING ICE: EXO.

e. MELTING ICE: ENDO.

f. BURNING: EXO.

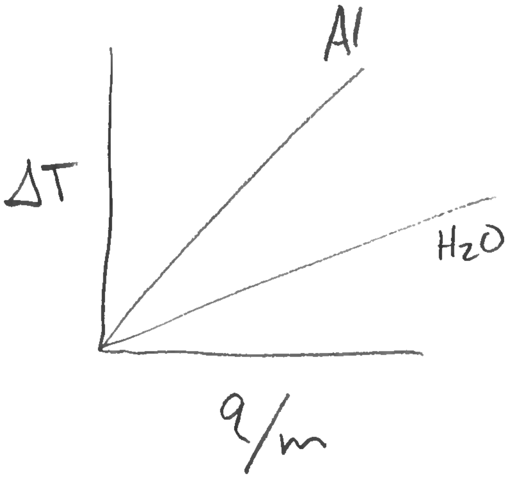
g. ACID/BASE RXN: EXO.

h. COLD PACK: ENDO.

i. HOT PACK: EXO.

(5) HEAT ADDED VS. ΔT: THE SMALLER THE HEAT CAPACITY (C), THE LARGER ΔT WILL BE FOR A GIVEN AMOUNT OF HEAT (q) AND MASS (m)

$q = mC\Delta T$ so $\boxed{\Delta T = \frac{1}{C} \cdot q/m \quad y = mx}$ → (WHERE q AND ΔT ARE VARIABLE, m IS HELD CONSTANT AND $\frac{1}{C}$ IS THE SLOPE OF A LINE)



$C_{Al} = 0.897 \frac{J}{g°C}$

$C_{H_2O} = 4.184 \frac{J}{g°C}$

$\Delta T = \frac{q}{mC}$

H_2O	Al
$\frac{100 J}{100g \cdot 4.184 \frac{J}{g°C}}$	$\frac{100 J}{100g \cdot 0.897 \frac{J}{g°C}}$
$+0.239°C$	$+1.11°C$

(7)

$q_{Fe} + q_{H_2O} = \emptyset$

$\boxed{\Delta T = T_f - T_i}$

$M_{Fe} C_{Fe} (T_f - T_i)_{Fe} + M_{H_2O} C_{H_2O} (T_f - T_i)_{H_2O} = \emptyset$ (C_{Fe} ?)

H_2O: $T_i = 25.0°C$, $T_f = 26.0°C$

$(22.4g)C(26.0°C - 101°C) + (182.9g)(4.184 \frac{J}{g°C})(26.0°C - 25.0°C) = \emptyset$

Fe: $T_i = 101°C$, $T_f = 26.0°C$

$(-1680 g \cdot °C)C + 761.5 J = \emptyset$

$\frac{(761.5 J)}{1680} = \frac{(1680 g \cdot °C)C}{1680}$

$\boxed{C = 0.453 \frac{J}{g°C}}$

(9) a. EXOTHERM.
b. $q_{soln} + q_{H_2O} = \emptyset$
$q = -20.5 kJ$
c. $-74.7 kJ/mol$

LET'S JUST DO ANSWERS FOR (8) & (9)

(8) a. ΔT IS POS. SO IT GAVE UP HEAT
b. EXOTHERM.
c. $-11.8 kJ$

(2)