2024 Fall Semester Final Examination
For General Chemistry I (Churchill)

Date: December 18(Wed),   Time Limit: 19:00 ~ 21:00

- **Write down your information neatly in the space provided below.**
- **Please print your Student ID in the upper right corner of every page.**

Professor's Name	Class	Student I.D. Number	Examinee Name

Problem	Points	Problem	Points	TOTAL points
1	/9	**6**	/17	**/100**
2	/6	**7**	/8	
3	/8	**8**	/6	
4	/6	**9**	/8	
5	/8	**10**	/24	

** This paper consists of 19 sheets with 10 problems (***pages 18 - 19***: Equation, constants, ***page 2***: claim form). Please check all page numbers before taking the exam. Write down your work and answers in the Answer sheet. Please write down the unit of your answer when applicable. You will receive 30% deduction for a missing unit.

NOTICE: SCHEDULES on RETURN and CLAIM of the MARKED EXAM PAPER.
(채점 답안지 분배 및 이의신청 일정)

1. Period, Location and Procedure

• Return and Claim Period: **December 20 (Friday, 12:00 ~ 14:00, 2 hrs)**
The claim is permitted only on this period. Keep that in mind!
• Location: Each designated room is found in the Creative Learning Bldg. (E11)

Class	Room(E11)
D	406

• Procedure
Rule 1: Students cannot bring their writing tools into the rooms (Use the pen provided by the TA only)
Rule 2: With or without claim, you must submit the paper back to the TA. (Do not go out of the room with it)

If you have any claims on it, write them on the claim form and attach it to the top of the exam paper with a stapler. Give them to your TA.

WARNING!!
If you deliberately alter any original answers or insert something on your marked paper to achieve a better grade, you will get an F grade for this course. Or if you don't keep the rules above, we will regard it as a kind of cheating and give you 0 points. So please don't cheat.

2. Final Confirmation

1) Period: ***December 21 (Sat.) ~ December 22 (Sun.)***
2) Procedure: During this period, you can check the final score of the examination *on the website* again.
(No additional corrections. If there was no change in your score after reasoning, the claims were not accepted.)
***** For further information, please visit General Chemistry website at www.gencheminkaist.pe.kr***

1. (9 points) Answer the following questions:

(a) (5 points)Which of the following molecular formulas represent a molecule that is certainly chiral? Which ones are not chiral or not necessarily chiral?

A. CHBrClF
B. $C_2Cl_3F_3$
C. $Fe(en)_3^{3-}$ (*en* = ethylenediamine)
D. $FeEDTA^{1-}$
E. $FeBr_3(CO)_3$

(b) (4 points)You have seen the structure of "cubane," C_8H_8. What are the main features of this interesting hydrocarbon in terms of its chemical bonds and real-life applications?

(answers)

(1)
A. CHBrClF – chiral
B. $C_2Cl_3F_3$ – not chiral
C. $Fe(en)_3^{3-}$ chiral
D. $FeEDTA^{3-}$ chiral
E. $FeBr_3(CO)_3^-$ not chiral

(2)
Bond strain: All C-C-C bond angles present in this molecule are measured to be ~90 deg. Such sp^3 hybridized bonds should be at or near 109.5 degrees. It is an experimental energetic material; an explosive but not widely used like TNT or nitroglycerin. Cubane can be considered a kind of fuel, requiring oxidant for functioning.

2. (**6 points**)(a) Table 8.7 from our text is shown below. Please fill in the items in the blank columns. Fill in the missing six hybrid orbital entries and six configurations of the complexes according to the coordination number. Allow the examples provided to help you.

TABLE 8.7 Examples of Hybrid Orbitals and Bonding in Complexes

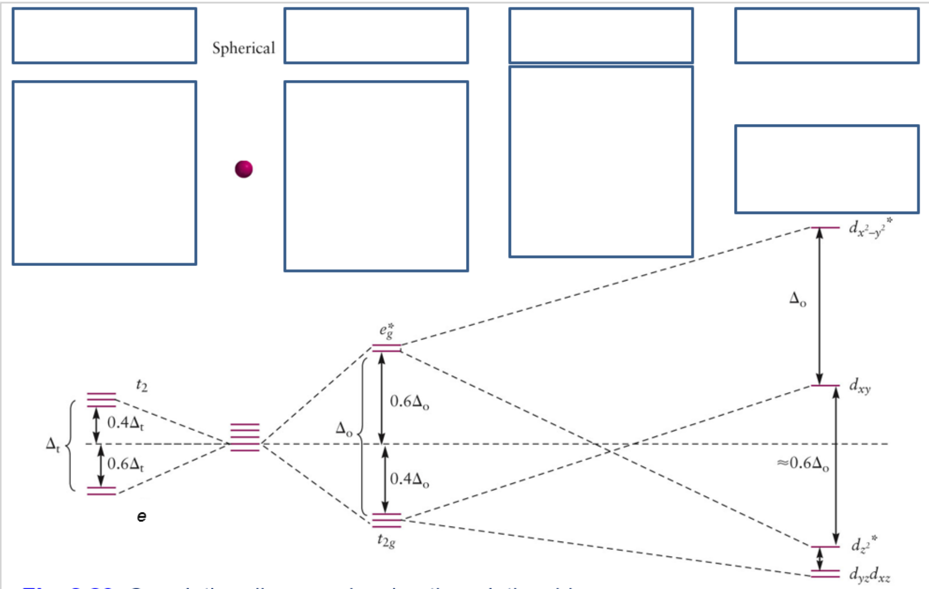
Coordination Number	Hybrid Orbital	Configuration	Examples
2			$[Ag(NH_3)_2]^+$
3			BF_3, NO_3^-, $[Ag(PR_3)_3]^+$
4			$Ni(CO)_4$, $[MnO_4]^-$, $[Zn(NH_3)_4]^{2+}$
4			$[Ni(CN)_4]^{2-}$, $[Pt(NH_3)_4]^{2+}$
5			TaF_5, $[CuCl_5]^{3-}$, $[Ni(PEt_3)_2Br_3]$
6			$[Co(NH_3)_6]^{3+}$, $[PtCl_6]^{2-}$

Answer

TABLE 8.7 Examples of Hybrid Orbitals and Bonding in Complexes

Coordination Number	Hybrid Orbital	Configuration	Examples
2	sp	Linear	$[Ag(NH_3)_2]^+$
3	sp^2	Trigonal planar	BF_3, NO_3^-, $[Ag(PR_3)_3]^+$
4	sp^3	Tetrahedral	$Ni(CO)_4$, $[MnO_4]^-$, $[Zn(NH_3)_4]^{2+}$
4	dsp^2	Square planar	$[Ni(CN)_4]^{2-}$, $[Pt(NH_3)_4]^{2+}$
5	dsp^3	Trigonal bipyramidal	TaF_5, $[CuCl_5]^{3-}$, $[Ni(PEt_3)_2Br_3]$
6	d^2sp^3	Octahedral	$[Co(NH_3)_6]^{3+}$, $[PtCl_6]^{2-}$

3. (**8 points**) Considering the energy diagram of the d-orbitals in different crystal field splittings, provide the geometric name of the crystal fields and draw a sketch describing how the ligands are organized in each type of crystal fields around the central atom.



Name of the crystal field

Draw a sketch

Fig. 8.20. Correlation diagram showing the relationships among *d*-orbital energy levels in crystal fields of different symmetries.

Answer

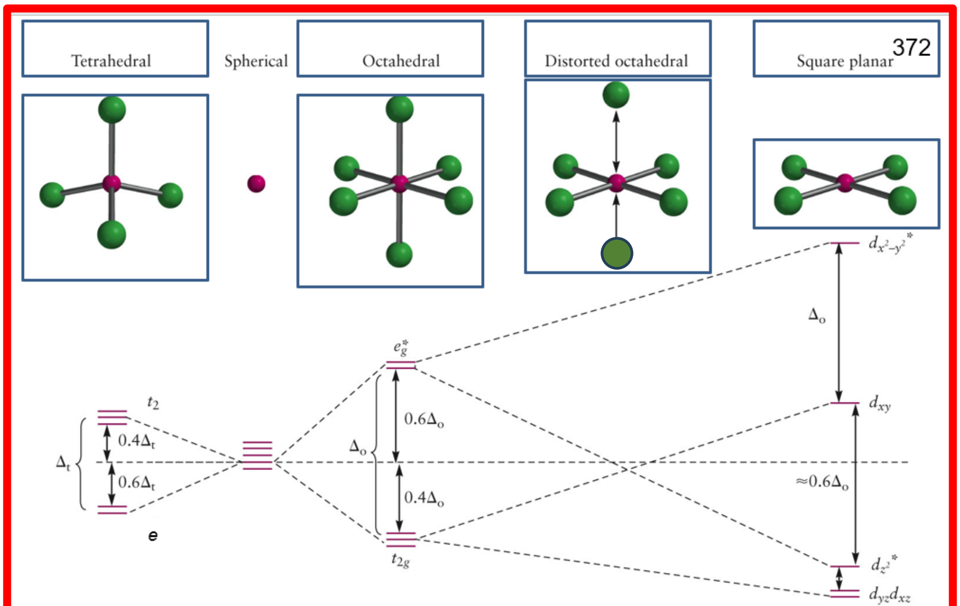


Fig. 8.20. Correlation diagram showing the relationships among *d*-orbital energy levels in crystal fields of different symmetries.

4. (**6 points total**) (a) (3 points) We learned about the "spectrochemical series for ligands." Please depict this set of monodentate ligands in the correct order of increasing crystal field strength using (<) symbols.

Ligand list: Br^-, CN^-, H_2O, F^-, NH_3, NCS^-, Cl^-, en, CO, I^-, OH^-

(b) (3 points) Briefly describe the indication of the "spectrochemical series for ligands" in the crystal field theory.

Answers:

(a)

$$I^- < Br^- < Cl^- < F^-, OH^- < H_2O < \ :NCS^- < NH_3 < en < CO, CN^-$$

Weak-field ligands (high spin) Intermediate-field ligands Strong-field ligands (low spin)

(b) "~ An ordering of ligands according to their ability to cause crystal field splittings."

5. (8 points) As you saw directly from our lecture: Concentrated nitric acid acts on copper to give nitrogen dioxide and dissolved copper ions according to the **non-balanced** chemical equation (below), suppose that 6.80 g copper is consumed in this reaction, and that the NO_2 is collected at a pressure of 0.970 atm and a temperature of 45°C. Calculate the volume of NO_2 produced.

$Cu(s) + H^{+}(aq) + NO_3^{-}(aq) \rightarrow NO_2(g) + Cu^{2+}(aq) + H_2O(l)$

Answer:

Balancing the equation gives it in a new form:

$Cu(s) + 4H^{+}_{(aq)} + 4NO_3^{-}{}_{(aq)} \rightarrow 2NO_{2(g)} + Cu(NO_3)_{2\,(aq)} + 2H_2O_{(l)}$

Computing:

$$\frac{6.80\ g\ Cu}{63.55\ g\ mol^{-1}} = 0.107\ mol\ Cu \qquad 0.107\ mol\ Cu \times \frac{2\ mol\ NO_2}{1\ mol\ Cu} = 0.214\ mol\ NO_2$$

$$V = \frac{nRT}{P} = \frac{(0.214\ mol)(0.08206\ L\ atm\ mol^{-1}K^{-1})(273.15 + 45)K}{0.970\ atm} = 5.76\ L$$

6. (17 points total) Ideal versus real gases. (a) (4 points) Which of these four things does an ideal gas fail to do based on the theory (**pick one or more**). Then provide a short answer.

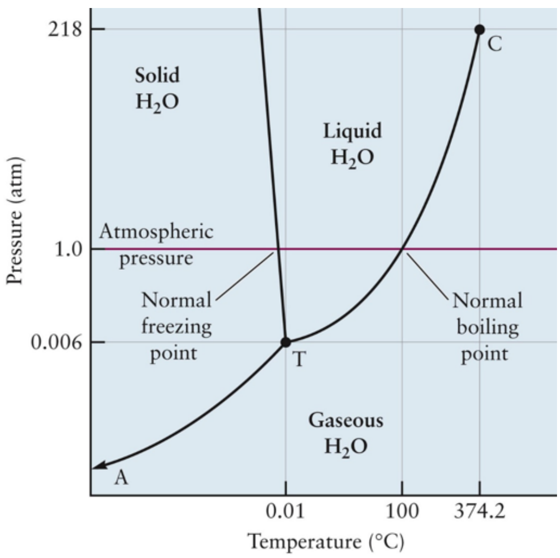
A. Liquifying?
B. Solidifying?
C. Pressurizing?
D. Heating?

(b) (5 points) Depict the "van der Waals equation." Compared to the ideal gas law, which 2 factors are additional factors? Explain.

(c) (4 points) The following sentences describe the kinetic theory of gases. Mark each argument as true (O) or false (X).

A. The kinetic theory Involves the Boltzmann constant.
B Has a temperature dependence.
C There is a mean path the particle takes.
D It can only contact the walls and not with fellow particles.

(d) (4 points) In a given phase diagram of a substance, what happens at the critical point of a substance (H_2O phase diagram shown below; we saw a video for CO_2)?



Answer:

a.

a Liquifying? Yes, it Fails
b Solidifying? Yes, it Fails
c Pressurizing? Allowable
d Heating? Allowable

b.

- Van der Waals equation:

$$\left(P + a\frac{n^2}{V^2}\right)(V - nb) = nRT$$

a: atm L^2 mol^{-2}
b: L mol^{-1}
R: L atm mol^{-1} K^{-1}

- $$z = \frac{PV}{nRT} = \frac{V}{V - nb} - \frac{a}{RT}\frac{n}{V} = \frac{1}{1 - \frac{bn}{V}} - \frac{a}{RT}\frac{n}{V}$$

Repulsive forces (through b) increase z above 1.
Attractive forces (through a) reduce z.

c. True or false:

The kinetic theory Involves the Boltzmann constant. (O)
Has a temperature dependence. (O)
There is a mean path the particle takes. (O)
It can only contact the walls and not with fellow particles. (X)

(d) As we saw in the video, in the chamber as it is heated, the meniscus disappears between the liquid and gas and a supercritical fluid exists.

7. (8 points) As we discussed, referring to the pairs of reactants below, kindly draw the expected products. Predict **whether products will be formed preferentially** based on our discussion of the Hard-Soft Acid Base Theory. (HSAB Theory). Refer to the table below from our text to help you make your prediction.

A: $Cr(CN)_2$ (s) + $Cd(OH)_2$ (s)
B: HgF_2 (g) + BeI_2 (g)
C: CaF_2 (s) + CdI_2 (s)
D: AgBr (s) + I^- (aq)

TABLE 8.2

Classification of Lewis Acids and Bases†

	Hard	Borderline	Soft
Acids	H^+, Li^+, Na^+, K^+ Be^{2+}, Mg^{2+}, Ca^{2+} Cr^{2+}, Cr^{3+}, Al^{3+} SO_3, BF_3	Fe^{2+}, Co^{2+} Ni^{2+} Cu^{2+} Zn^{2+} Pb^{2+} SO_2, BBr_3	Cu^+, Ag^+ Au^+, Tl^+, Hg^+ Pd^{2+}, Cd^{2+}, Pt^{2+} HG^{2+} BH_3
Bases	F^-, OH^- H_2O, NH_3 CO_3^{2-}, NO_3^-, O^{2-} SO_4^{2-}, PO_4^{3-}, ClO_4^-	$\underline{N}O_2^-$, SO_3^{2-}, Br^- N_3^-, N_2 C_6H_5N, $SC\underline{N}^-$	H^-, R^-, $\underline{C}N^-$, $\underline{C}O$, I^- CN^-, R_3P, C_6H_6 R_2S

†The underlined element identifies the electron pair donor if there is more than one possible choice.

Answers:

A $Cr(CN)_2$ (s) + $Cd(OH)_2$ (s) → $Cd(CN)_2$ (s) + $Cr(OH)_2$ (s) YES, It goes to the right!!
B HgF_2 (g) + BeI_2 (g) → BeF_2 (g) + HgI_2 (g) YES, It goes to the right!!
C CaF_2 (s) + CdI_2 (s) → CaI_2 (s) + CdF_2 (s) NO!!
D AgBr (s) + I^- (aq) → AgI (s) + Br^- (aq) YES, It goes to the right!!

8. (6 points total). (a) (4 points) Give two examples of "disproportionation." One using H_2O and a second separate example using the Cu^+ ion.

(b) (2 points) Show the autoionization of water:

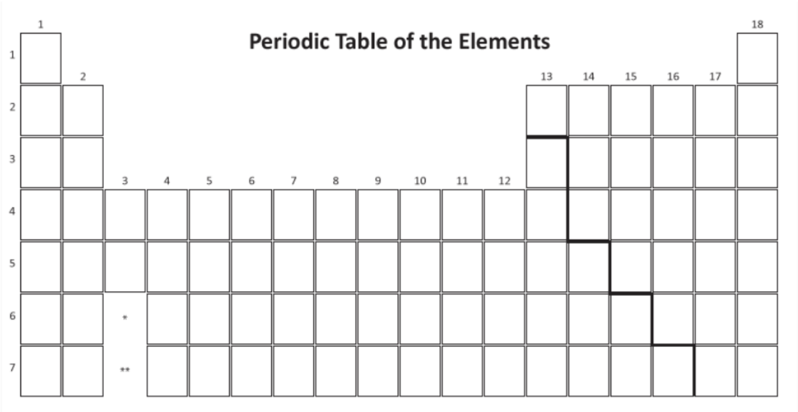
(answers)

$2H_2O_{2(aq)} \rightarrow O_{2(g)} + 2H_2O_{(aq)}$

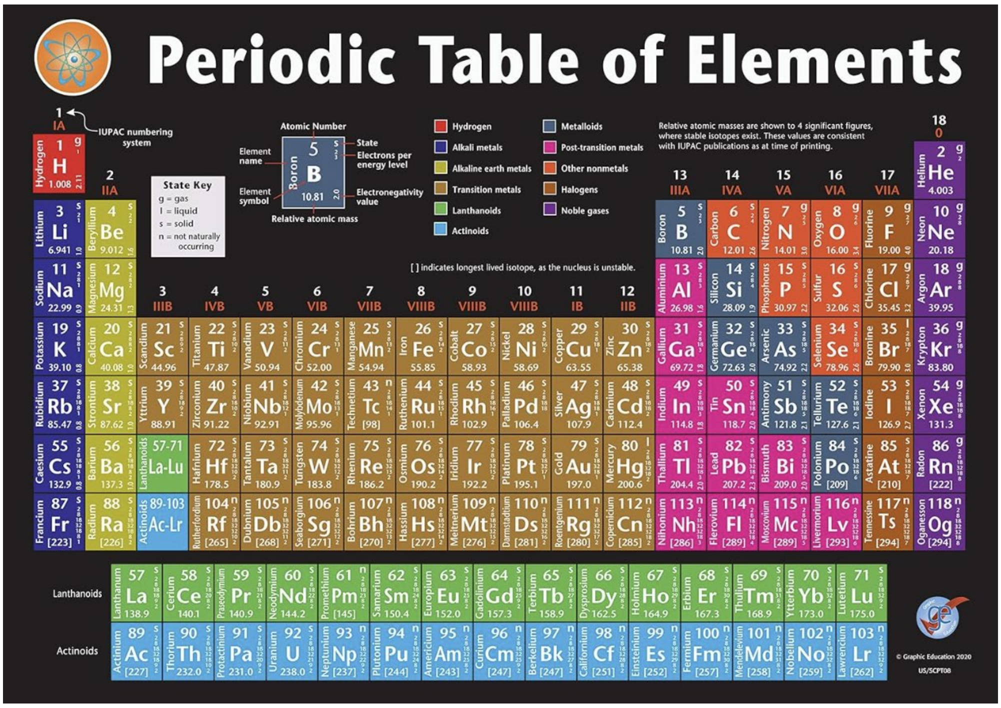
$Cu^+_{(aq)} \rightarrow Cu^{2+}_{(aq)} + Cu^0_{(s)}$

$H_2O \rightarrow$ H+ OH-

9. (8 points) Please provide the elemental symbols correctly into the blank Periodic table below. Provide at least the symbols for the d-block and p-block elements:



Answer:

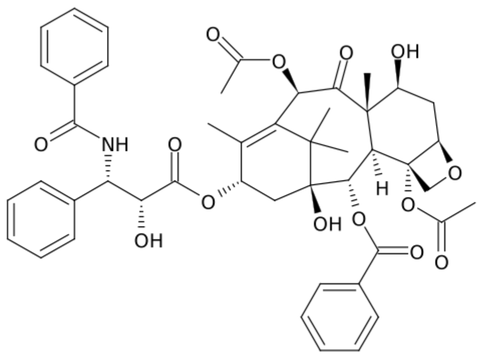


First 10 elements 4 points

10. (12 points total) (a) (3 points) List the following substances in order of increasing boiling point: SO_2, He, HF CaF_2 Ar.

(b) (4 points) Draw a structure for the acetic acid dimer (CH_3CO_2H) in the vapor phase. Explain what might be expected in the liquid phase.

c. (5 points) Identify the functional groups in the following compound called Paclitaxel or Taxol Indicate your identifications by using the grid below.



Answer Grid:

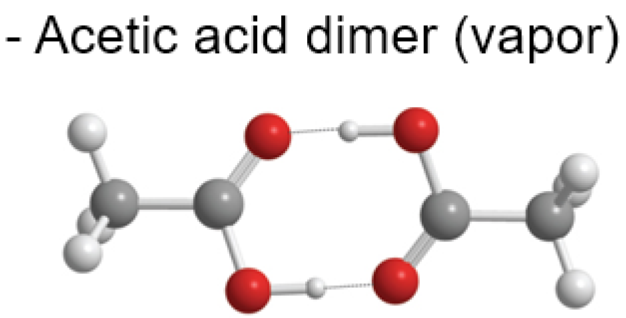
Name	Sketch or molecular formula	Total number of functional groups

Answers:

(a) The correct order based on knowledge of intermolecular forces is :

He < Ar < SO_2 < HF < CaF_2

(b) This structure predominates in non-polar solvents, but not in dilute aqueous solution. Explain.



12 Acetic acid dimer

- Try to draw arrows that indicate lone pair donation. Arrows should be draw from the oxygen to the proton – O→H.
- Further explanation: In dilute aqueous solutions, dimer are broken up by stronger hydrogen bonding to the solvent H_2O which is predominant.
- There is also dissociation of the proton – isomerism.

(c)

Name	Sketch or molecular formula	Number
Alcohol	R-OH	3
Amide	R-C(O)NR’	1

Ether	R-O-R’	1
Ketone	R-C(O)R’	1
ester	R-C(O)OR’	4
Other??		

d. (d and e: 12 points total) (a) (5 points) Please balance this "redox" equation below from our notes based on our discussion. Show each and all steps as we discussed.

$CuS_{(s)} + NO_3^-{}_{(aq)} \rightarrow Cu^{2+}{}_{(aq)} + SO_4^{2-}{}_{(aq)} + NO_{(g)}$ in aqueous nitric acid

(answer)

- **Step 1.** Divide into two unbalanced **half-reactions**.

  $CuS \rightarrow Cu^{2+} + SO_4^{2-}$

  $NO_3^- \rightarrow NO$

- **Step 2.** Balance **all elements** except oxygen and hydrogen.

  Already done.

- **Step 3.** Balance **oxygen** by adding H_2O.

  $CuS + 4\ H_2O \rightarrow Cu^{2+} + SO_4^{2-}$

  $NO_3^- \rightarrow NO + 2\ H_2O$

- **Step 4.** Balance **hydrogen**.

  ~ Add H_3O^+ / H_2O (acidic) or H_2O / OH^- (basic)

  $CuS + 8\ H_2O + 4\ H_2O \rightarrow Cu^{2+} + SO_4^{2-} + 8\ H_3O^+$

  $NO_3^- + 4\ H_3O^+ \rightarrow NO + 2\ H_2O + 4\ H_2O$

- **Step 5.** Balance **charge** using e^-.

  $CuS + 12\ H_2O \rightarrow Cu^{2+} + SO_4^{2-} + 8\ H_3O^+ + 8\ e^-$

  $NO_3^- + 4\ H_3O^+ + 3\ e^- \rightarrow NO + 6\ H_2O$

- **Step 6.** Combine the two half-reactions **canceling** e^-.

  $3 \times (\ CuS + 12\ H_2O \rightarrow Cu^{2+} + SO_4^{2-} + 8\ H_3O^+ + 8\ e^-\ )$

  $8 \times (\ NO_3^- + 4\ H_3O^+ + 3\ e^- \rightarrow NO + 6\ H_2O\ )$

$$3\ CuS + 8\ NO_3^- + 8\ H_3O^+ \rightarrow 3\ Cu^{2+} + 3\ SO_4^{2-} + 8\ NO + 12\ H_2O$$

–2 +5 +6 +2

(e) **(7 Points)**. Fill in the boxes with the correct intermolecular forces described by the equations (relationship to r) or vice versa to make a correct pair as we discussed (directly from your notes).

◈ INTERACTIONS

- ▶ [ ]: $E_P = \dfrac{Q_1 Q_2}{4\pi\varepsilon_0 r}$
- ▶ Ion – Dipole: [ ]
- ▶ [ ] $E_P \propto -\dfrac{\mu_1 \mu_2}{r^3}$
  - ▷ Rotating polar gas molecules*: [ ]
- ▶ [ ]: $E_P \propto -\dfrac{\mu_1^2 \alpha_2}{r^6}$
- ▶ London (dispersion)*: (Induced dipole – Induced dipole) [ ]

* [ ] $E_P \propto -\dfrac{C}{r^6}$

Answers:

◈ INTERACTIONS

- ▶ Ion – Ion (Coulomb): $E_P = \dfrac{Q_1 Q_2}{4\pi\varepsilon_0 r}$
- ▶ Ion – Dipole: $E_P \propto -\dfrac{|z|\mu}{r^2}$
- ▶ Dipole – Dipole: $E_P \propto -\dfrac{\mu_1 \mu_2}{r^3}$
  - ▷ Rotating polar gas molecules*: $E_P \propto -\dfrac{\mu_1 \mu_2}{r^6}$
- ▶ Dipole – Induced dipole*: $E_P \propto -\dfrac{\mu_1^2 \alpha_2}{r^6}$
- ▶ London (dispersion)*: (Induced dipole – Induced dipole) $E_P \propto -\dfrac{\alpha_1 \alpha_2}{r^6}$

* Van der Waals interactions $E_P \propto -\dfrac{C}{r^6}$

Physical Constants

Avogadro's number	N_A = 6.02214179 x 10^{23} mol^{-1}
Bohr radius	a_0 = 0.52917720859 Å = 5.2917720859x10^{-11} m
Boltzmann's constant	K_B = 1.3806504 x 10^{-23} J K^{-1}
Electronic charge	e = 1.602176487 x 10^{-19} C
Faraday constant	F = 96485.3399 C mol^{-1}
Masses of fundamental particles:	
Electron	m_e = 9.10938215 x 10^{-31} kg
Proton	m_P = 1.672621637 x 10^{-27} kg
Neutron	m_n= 1.674927211 x 10^{-27} kg
Permittivity of vacuum	ε_o = 8.854187817 x 10^{-12} C^{-2} J^{-1} m^{-1}
Planck's constant	h = 6.62606896 x 10^{-34} J s
Ratio of proton mass to electron mass	m_P / m_e = 1836.15267247
Speed of light in a vacuum	c = 2.99792458 x 10^8 m s^{-1} (exactly)
Standard acceleration of terrestrial gravity	g = 9.80665 m s^{-2} (exactly)
Universal gas constant	R = 8.314472 J mol^{-1} K^{-1} = 0.0820574 L atm mol^{-1} K^{-1}

Values are taken from the 2006 CODATA recommended values,
as listed by the National Institute of Standards and Technology.

Conversion factors

Ångström	1 Å= 10^{-10} m
Atomic mass unit	1 u = 1.660538782 x 10^{-27} kg
	1 u = 1.492417830 x 10^{-10} J = 931.494028 MeV (energy equivalent form $E = mc^2$)
Calorie	1 cal = 4.184 J (exactly)
Electron volt	1 eV = 1.602177 x 10^{-19} J = 96.485335 kJ mol^{-1}
Foot	1 ft = 12 in = 0.3048 m (exactly)
Gallon (U. S.)	1 gallon = 4 quarts = 3.785412 L (exactly)
Liter	1 L = 10^{-3} m^3 = 10^3 cm^3 (exactly)

Liter-atmosphere	1 L atm = 101.325 J (exactly)
Metric ton	1 t = 1000 kg (exactly)
Pound	1 lb = 16 oz = 0.4539237 kg (exactly)
Rydberg	1 Ry = 2.17987197 x 10^{-18}J = 1312.7136 kJ mol^{-1} = 13.60569193 eV
Standard atmosphere	1 atm = 1.01325 x 10^5 Pa = 1.01325 x 10^5 kg m^{-1} s^{-2} (exactly)
Torr	1 torr = 133.3224 Pa