**NAME (Print):** _____

**SIGNATURE:** _____

**Chemistry 310M/318M**
**Dr. Brent Iverson**
**Final exam**
**December 7, 2011**

**Please print the first three letters of your last name in the three boxes**

| | | |
|---|---|---|
| | | |

**Please Note:** This test may be a bit long, but there is a reason. I would like to give you a lot of little questions, so you can find ones you can answer and show me what you know, rather than just a few questions that may be testing the one thing you forgot. **I recommend you look the exam over and answer the questions you are sure of first**, then go back and try to figure out the rest. Also make sure to **look at the point totals** on the questions as a guide to help budget your time.

## You must have your answers written in PERMANENT ink if you want a regrade!!!! This means no test written in pencil or ERASABLE INK will be regraded.

**Please note: We routinely xerox a number of exams following initial grading to guard against receiving altered answers during the regrading process.**

**FINALLY, DUE TO SOME UNFORTUNATE RECENT INCIDENCTS YOU ARE NOT ALLOWED TO INTERACT WITH YOUR CELL PHONE IN ANY WAY. IF YOU TOUCH YOUR CELL PHONE DURING THE EXAM YOU WILL GET A "0" NO MATTER WHAT YOU ARE DOING WITH THE PHONE. PUT IT AWAY AND LEAVE IT THERE!!!**

| Page | Points | |
|---|---|---|
| 1 | | (29) |
| 2 | | (22) |
| 3 | | (14) |
| 4 | | (15) |
| 5 | | (-) |
| 6 | | (-) |
| 7 | | (-) |
| 8 | | (16) |
| 9 | | (19) |
| 10 | | (21) |
| 11 | | (-) |
| 12 | | (22) |
| 13 | | (25) |
| 14 | | (42) |
| 15 | | (35) |
| 16 | | (30) |
| 17 | | (17) |
| 18 | | (22) |
| 19 | | (16) |
| 20 | | (12) |
| 21 | | (8) |
| 22 | | (8) |
| Total | | (373) |
| % | | |
| T Score | | |
| HW | | |
| Total Grade | | |

(HW score + Exam Grade) ⟹

## Honor Code

The core values of the University of Texas at Austin are learning, discovery, freedom, leadership, individual opportunity, and responsibility. Each member of the University is expected to uphold these values through integrity, honesty, trust, fairness, and respect toward peers and community.

_____

(Your signature)

The first semester of Organic Chemistry is a journey that begins with a review of material you have seen, transitions to the study of organic molecules, then settles in with a long discussion of reactions and their mechanisms. The pace accelerates through the chapters until we finish with the chemistry of epoxides. Solving organic synthesis problems requires not only a firm command of the many reactions and mechanisms we have presented, but also high level problem solving skills and a spark of creativity. We finished this part of the journey with probably the most useful thing you will learn in Organic Chemistry, the science behind MRI. You have all come a long way since late August when you first came to class. It is my sincere hope that this final serves to affirm that you have completed this journey successfully and caught the Organic Chemistry wave!

As you go through the test, use good test taking strategy by:

1) Remaining as relaxed and calm as possible
2) Working problems worth the most points first
3) Concentrate on finishing all the problems you are most certain about
4) Leave the ones you have doubts about for last
5) Do not second guess yourself

*Have a safe holiday and remember to exercise every chance you get. If you stay in shape throughout your life, you will thank yourself more than you can imagine!!!*

Brent Iverson

*Use this page to write down your roadmap if you would like.*

Use this page for scratch if you would like. For your reference, here are the Golden Rules of Chemistry:

1. Atoms prefer filled valence shells. 2. The most important question in chemistry is "Where are the electrons?" 3. Nature hates unpaired electrons. 4. Nature hates localized charges. 5. Most reactions involve nucleophiles (molecules with a location of particularly high electron density) attacking electrophiles (molecules with a location of particularly low electron density). 6. Steric interactions (atoms bumping into each other) can prevent reactions by keeping the reactive atoms away from each other. 7. Pi electrons prefer to be delocalized over as many adjacent $sp^2$ hybridized atoms (or $sp^1$ hybridized atoms in some cases) as possible, and aromaticity is the most stable form of pi electron delocalization.

# PERIODIC TABLE OF THE ELEMENTS

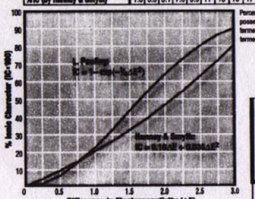
## ▼ Elementary Subatomic Particles

| | Electron | Proton | Neutron | Photon | Neutrino |
|---|---|---|---|---|---|
| Symbol | e | P | n | γ | ν |
| Rest mass (kg) | 9.109389?(54) x 10⁻³¹ | 1.6726231(10) x 10⁻²⁷ | 1.6749280(10) x 10⁻²⁷ | 0 | = 0 |
| Molar mass (kg/mol) | 5.48579903(13) x 10⁻⁷ | 1.00727647?(12) x 10⁻³ | 1.00866490?(4) x 10⁻³ | 0 | = 0 |
| Particle-electron mass ratio | 1 | 1836.152701(37) | 1838.683662(40) | 0 | = 0 |
| Particle-proton mass ratio | 5.44617013(11) x 10⁻⁴ | 1 | 1.001378404(9) | 0 | = 0 |
| Particle-neutron mass ratio | 5.438673?x10⁻⁴ | 0.998624 | 1 | 0 | = 0 |
| Specific charge (C/kg) | −1.75881962(53) x 10⁺¹¹ | 9.5788309(29) x 10⁺⁷ | 0 | 0 | 0 |
| Radius (m) | < 1 x 10⁻¹⁸ | 8 x 10⁻¹⁶ | 8 x 10⁻¹⁶ | 0 | = 0 |
| Spin quantum number | 1/2 | 1/2 | 1/2 | 1 | 1/2 |
| Compton wavelength (m) | 2.4263105?(22) x 10⁻¹² | 1.3214002(12) x 10⁻¹⁵ | 1.3195911?(12) x 10⁻¹⁵ | – | – |
| Magnetic moment (J/T); μ | 928.47701(31) x 10⁻²⁶ | 1.4106076?(47) x 10⁻²⁶ | 0.9662376?(40) x 10⁻²⁶ | 0 | 0 |
| In Bohr magnetons; $\mu/\mu_B$ | 1.001159652193(10) | 1.521032202(15) x 10⁻³ | 1.04187563(25) x 10⁻³ | 0 | 0 |
| In nuclear magnetons; $\mu/\mu_N$ | 1836.282000(37) | 2.792847386(63) | 1.91304275(45) | 0 | 0 |

Elementary particles are the fundamental constituents of energy and matter. The positron ($e^+$) is a positive-energy particle which has the same mass as an ordinary electron. The antineutrino ($\bar{\nu}$) has similar properties as that of a neutrino ($\nu$) except its spin is directed along its direction of motion, whereas the neutrino's spin is always opposite to the direction of motion. Negative beta decay is the transformation of a neutron into a proton, a beta particle (negative electron) and a antineutrino ($n \rightarrow p + e^- + \bar{\nu}$). Positive beta decay involves the transformation of a proton into a neutron, a positron and a neutrino ($p \rightarrow n + \beta^+ + \nu$). The magnetic moment ($\mu_l$) of a particle can also be expressed as a dimensionless quantity by dividing it with either the Bohr magneton ($\mu_B$ = 9.2740154(31) x $10^{-24}$ J/T) or the nuclear magneton ($\mu_N$ = 5.0507866(17) x $10^{-27}$ J/T).

## ▼ % Ionic Character of a Single Chemical Bond

| Difference in Electronegativity | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 | 1.0 | 1.1 | 1.2 | 1.3 | 1.4 | 1.5 | 1.6 | 1.7 | 1.8 | 1.9 | 2.0 | 2.1 | 2.2 | 2.3 | 2.4 | 2.5 | 2.6 | 2.7 | 2.8 | 2.9 | 3.0 | 3.1 | 3.2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| %IC (by L. Pauling) | 0.2 | 1.0 | 2.2 | 3.8 | 6.1 | 8.6 | 12 | 15 | 18 | 22 | 26 | 30 | 34 | 39 | 43 | 47 | 51 | 56 | 59 | 63 | 67 | 70 | 73 | 76 | 79 | 82 | 84 | 86 | 88 | 89 | 91 | 92 |
| %IC (by Hanney & Smyth) | 1.0 | 3.3 | 5.1 | 7.0 | 8.9 | 11 | 13 | 15 | 17 | 20 | 22 | 24 | 27 | 29 | 32 | 35 | 37 | 40 | 43 | 46 | 49 | 52 | 55 | 58 | 62 | 65 | 68 | 72 | 76 | 80 | 83 | 87 |




Percent ionic character describes the nature of a bond. Bonds possessing 50% or greater ionic character are commonly termed ionic; bonds with less than 50% ionic character are termed covalent. Pauling's equation was modified by Hanney & Smyth in order to achieve better agreement between experimental and calculated values. Transition from ionic to covalent binding is usually accompanied by a reduction in electrical conductance, melting point and boiling point.

| 1 IA | | | | | | | | | | | | | | | | | | 18 VIII O |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.00794<br>−259.34<br>−252.87<br>0.0899<br>2.20<br>13.598<br>1s¹<br>**1**<br>**H**<br>Hydrogen | 2 IIA | | | | | | | | | | 13 IIIB IIIA | 14 IVB IVA | 15 VB VA | 16 VIB VIA | 17 VIIB VIIA | 4.002602<br>−272.2 (26 atm)<br>−268.93<br>0.1785<br>–<br>24.587<br>1s²<br>**2**<br>**He**<br>Helium |
| 6.941<br>180.5<br>1342<br>0.534<br>0.98<br>5.392<br>[He]2s¹<br>**3**<br>**Li**<br>Lithium | 9.012182<br>1287<br>2471<br>1.8477<br>1.57<br>9.322<br>[He]2s²<br>**4**<br>**Be**<br>Beryllium | | | | | | | | | | 10.811<br>2075<br>4000<br>2.31<br>2.04<br>8.298<br>[He]2s²2p¹<br>**5**<br>**B**<br>Boron | 12.011<br>4492*<br>3825*<br>2.25<br>2.55<br>11.260<br>[He]2s²2p²<br>**6**<br>**C**<br>Carbon | 14.00674<br>−210.00<br>−195.79<br>1.25046<br>3.04<br>14.534<br>[He]2s²2p³<br>**7**<br>**N**<br>Nitrogen | 15.9994<br>−218.79<br>−182.95<br>1.429<br>3.44<br>13.618<br>[He]2s²2p⁴<br>**8**<br>**O**<br>Oxygen | 18.9984032<br>−219.62<br>−188.12<br>1.69<br>3.98<br>17.422<br>[He]2s²2p⁵<br>**9**<br>**F**<br>Fluorine | 20.1797<br>−248.59<br>−246.08<br>0.9002<br>–<br>21.564<br>[He]2s²2p⁶<br>**10**<br>**Ne**<br>Neon |
| 22.989768<br>97.72<br>883<br>0.97<br>0.93<br>5.139<br>[Ne]3s¹<br>**11**<br>**Na**<br>Sodium | 24.3050<br>650<br>1090<br>1.74<br>1.31<br>7.646<br>[Ne]3s²<br>**12**<br>**Mg**<br>Magnesium | 3 IIIA IIIB | 4 IVA IVB | 5 VA VB | 6 VIA VIB | 7 VIIA VIIB | 8 VIIIA VIII | 9 VIIIA VIII | 10 VIIIA VIII | 11 IB IB | 12 IIB IIB | | | | | | | 26.981539<br>660.32<br>2519<br>2.702<br>1.61<br>5.986<br>[Ne]3s²3p¹<br>**13**<br>**Al**<br>Aluminum | 28.0855<br>1414<br>3265*<br>2.33<br>1.90<br>8.151<br>[Ne]3s²3p²<br>**14**<br>**Si**<br>Silicon | 30.973762<br>44.15<br>277<br>1.82<br>2.19<br>10.486<br>[Ne]3s²3p³<br>**15**<br>**P**<br>Phosphorus | 32.066<br>−115.21<br>444.60<br>2.07<br>2.58<br>10.360<br>[Ne]3s²3p⁴<br>**16**<br>**S**<br>Sulfur | 35.4527<br>−101.5<br>−34.04<br>3.214<br>3.16<br>12.967<br>[Ne]3s²3p⁵<br>**17**<br>**Cl**<br>Chlorine | 39.948<br>−189.35<br>−185.85<br>1.784<br>–<br>15.759<br>[Ne]3s²3p⁶<br>**18**<br>**Ar**<br>Argon |
| 39.0983<br>63.38<br>759<br>0.86<br>0.82<br>4.341<br>[Ar]4s¹<br>**19**<br>**K**<br>Potassium | 40.078<br>842<br>1484<br>1.54<br>1.00<br>6.113<br>[Ar]4s²<br>**20**<br>**Ca**<br>Calcium | 44.955910<br>1541<br>2830<br>2.989<br>1.36<br>6.54<br>[Ar]3d¹4s²<br>**21**<br>**Sc**<br>Scandium | 47.88<br>1660<br>3287<br>4.5<br>1.54<br>6.82<br>[Ar]3d²4s²<br>**22**<br>**Ti**<br>Titanium | 50.9415<br>1910<br>3407<br>5.96<br>1.63<br>6.74<br>[Ar]3d³4s²<br>**23**<br>**V**<br>Vanadium | 51.9961<br>1907<br>2671<br>7.20<br>1.66<br>6.766<br>[Ar]3d⁵4s¹<br>**24**<br>**Cr**<br>Chromium | 54.93805<br>1246<br>2061<br>7.47<br>1.55<br>7.435<br>[Ar]3d⁵4s²<br>**25**<br>**Mn**<br>Manganese | 55.847<br>1538<br>2861<br>7.86<br>1.83<br>7.870<br>[Ar]3d⁶4s²<br>**26**<br>**Fe**<br>Iron | 58.93320<br>1495<br>2927<br>8.92<br>1.88<br>7.86<br>[Ar]3d⁷4s²<br>**27**<br>**Co**<br>Cobalt | 58.6934<br>1455<br>2913<br>8.90<br>1.91<br>7.635<br>[Ar]3d⁸4s²<br>**28**<br>**Ni**<br>Nickel | 63.546<br>1084.62<br>2562<br>8.94<br>1.90<br>7.726<br>[Ar]3d¹⁰4s¹<br>**29**<br>**Cu**<br>Copper | 65.39<br>419.53<br>907<br>7.14 20°C<br>1.65<br>9.394<br>[Ar]3d¹⁰4s²<br>**30**<br>**Zn**<br>Zinc | 69.723<br>29.76<br>2204<br>6.095<br>1.81<br>5.999<br>[Ar]3d¹⁰4s²4p¹<br>**31**<br>**Ga**<br>Gallium | 72.61<br>938.25<br>2833<br>5.35<br>2.01<br>7.899<br>[Ar]3d¹⁰4s²4p²<br>**32**<br>**Ge**<br>Germanium | 74.92159<br>817*<br>614*<br>5.727 25°C<br>2.18<br>9.81<br>[Ar]3d¹⁰4s²4p³<br>**33**<br>**As**<br>Arsenic | 78.96<br>221<br>685<br>4.81<br>2.55<br>9.752<br>[Ar]3d¹⁰4s²4p⁴<br>**34**<br>**Se**<br>Selenium | 79.904<br>−7.2<br>58.8<br>3.119<br>2.96<br>11.814<br>[Ar]3d¹⁰4s²4p⁵<br>**35**<br>**Br**<br>Bromine | 83.80<br>−157.36<br>−153.22<br>3.74<br>–<br>13.999<br>[Ar]3d¹⁰4s²4p⁶<br>**36**<br>**Kr**<br>Krypton |
| 85.4678<br>38.31<br>688<br>1.532<br>0.82<br>4.177<br>[Kr]5s¹<br>**37**<br>**Rb**<br>Rubidium | 87.62<br>777<br>1382<br>2.6<br>0.95<br>5.695<br>[Kr]5s²<br>**38**<br>**Sr**<br>Strontium | 88.90585<br>1526<br>3336<br>4.469<br>1.22<br>6.38<br>[Kr]4d¹5s²<br>**39**<br>**Y**<br>Yttrium | 91.224<br>1855<br>4409<br>6.49<br>1.33<br>6.84<br>[Kr]4d²5s²<br>**40**<br>**Zr**<br>Zirconium | 92.90638<br>2477<br>4744<br>8.57<br>1.6<br>6.9<br>[Kr]4d⁴5s¹<br>**41**<br>**Nb**<br>Niobium | 95.94<br>2623<br>4639<br>10.2<br>2.16<br>7.099<br>[Kr]4d⁵5s¹<br>**42**<br>**Mo**<br>Molybdenum | (97.9072)<br>2157<br>4265<br>11.5<br>1.9<br>7.28<br>[Kr]4d⁵5s²<br>**43**<br>**Tc**<br>Technetium | 101.07<br>2334<br>4156<br>12.3<br>2.2<br>7.37<br>[Kr]4d⁷5s¹<br>**44**<br>**Ru**<br>Ruthenium | 102.90550<br>1964<br>3695<br>12.4<br>2.28<br>7.46<br>[Kr]4d⁸5s¹<br>**45**<br>**Rh**<br>Rhodium | 106.42<br>1554.9<br>2963<br>12.02<br>2.20<br>8.34<br>[Kr]4d¹⁰<br>**46**<br>**Pd**<br>Palladium | 107.8682<br>961.78<br>2162<br>10.5<br>1.93<br>7.576<br>[Kr]4d¹⁰5s¹<br>**47**<br>**Ag**<br>Silver | 112.411<br>321.07<br>767<br>8.642<br>1.69<br>8.993<br>[Kr]4d¹⁰5s²<br>**48**<br>**Cd**<br>Cadmium | 114.818<br>156.60<br>2072<br>7.30<br>1.78<br>5.786<br>[Kr]4d¹⁰5s²5p¹<br>**49**<br>**In**<br>Indium | 118.710<br>231.93<br>2602<br>7.28<br>1.96<br>7.344<br>[Kr]4d¹⁰5s²5p²<br>**50**<br>**Sn**<br>Tin | 121.757<br>630.63<br>1587<br>6.684 25°C<br>2.05<br>8.641<br>[Kr]4d¹⁰5s²5p³<br>**51**<br>**Sb**<br>Antimony | 127.60<br>449.51<br>988<br>6.25<br>2.1<br>9.009<br>[Kr]4d¹⁰5s²5p⁴<br>**52**<br>**Te**<br>Tellurium | 126.90447<br>113.7<br>184.4<br>4.93<br>2.66<br>10.451<br>[Kr]4d¹⁰5s²5p⁵<br>**53**<br>**I**<br>Iodine | 131.29<br>−111.75<br>−108.04<br>5.89<br>–<br>12.130<br>[Kr]4d¹⁰5s²5p⁶<br>**54**<br>**Xe**<br>Xenon |
| 132.90543<br>28.44<br>671<br>1.879<br>0.79<br>3.894<br>[Xe]6s¹<br>**55**<br>**Cs**<br>Cesium | 137.327<br>727<br>1897<br>3.594<br>0.89<br>5.212<br>[Xe]6s²<br>**56**<br>**Ba**<br>Barium | 138.9055<br>920<br>3455<br>6.146<br>1.10<br>5.577<br>[Xe]5d¹6s²<br>**57**<br>**La**<br>Lanthanum | 178.49<br>2233<br>4603<br>13.31<br>1.3<br>7.9<br>[Xe]4f¹⁴5d²6s²<br>**72**<br>**Hf**<br>Hafnium | 180.9479<br>3017<br>5458<br>16.6<br>1.5<br>7.89<br>[Xe]4f¹⁴5d³6s²<br>**73**<br>**Ta**<br>Tantalum | 183.84<br>3422<br>5555<br>19.35<br>2.36<br>7.98<br>[Xe]4f¹⁴5d⁴6s²<br>**74**<br>**W**<br>Tungsten | 186.207<br>3186<br>5596<br>20.5<br>1.9<br>7.88<br>[Xe]4f¹⁴5d⁵6s²<br>**75**<br>**Re**<br>Rhenium | 190.23<br>3033<br>5012<br>22.61<br>2.2<br>8.7<br>[Xe]4f¹⁴5d⁶6s²<br>**76**<br>**Os**<br>Osmium | 192.22<br>2446<br>4428<br>22.65<br>2.20<br>9.1<br>[Xe]4f¹⁴5d⁷6s²<br>**77**<br>**Ir**<br>Iridium | 195.08<br>1768.4<br>3825<br>21.45<br>2.28<br>9.0<br>[Xe]4f¹⁴5d⁹6s¹<br>**78**<br>**Pt**<br>Platinum | 196.96654<br>1064.18<br>2856<br>19.31<br>2.54<br>9.225<br>[Xe]4f¹⁴5d¹⁰6s¹<br>**79**<br>**Au**<br>Gold | 200.59<br>−38.83<br>356.73<br>13.546<br>2.00<br>10.437<br>[Xe]4f¹⁴5d¹⁰6s²<br>**80**<br>**Hg**<br>Mercury | 204.3833<br>304<br>1473<br>11.85<br>2.04<br>6.108<br>[Xe]4f¹⁴5d¹⁰6s²6p¹<br>**81**<br>**Tl**<br>Thallium | 207.2<br>327.46<br>1749<br>11.34<br>2.33<br>7.416<br>[Xe]4f¹⁴5d¹⁰6s²6p²<br>**82**<br>**Pb**<br>Lead | 208.98037<br>271.40<br>1564<br>9.78<br>2.02<br>7.289<br>[Xe]4f¹⁴5d¹⁰6s²6p³<br>**83**<br>**Bi**<br>Bismuth | (208.9824)<br>254<br>962<br>9.196<br>2.0<br>8.42<br>[Xe]4f¹⁴5d¹⁰6s²6p⁴<br>**84**<br>**Po**<br>Polonium | (209.9871)<br>302<br>337<br>–<br>2.2<br>–<br>[Xe]4f¹⁴5d¹⁰6s²6p⁵<br>**85**<br>**At**<br>Astatine | (222.0176)<br>−71<br>−61.7<br>9.73<br>–<br>10.748<br>[Xe]4f¹⁴5d¹⁰6s²6p⁶<br>**86**<br>**Rn**<br>Radon |
| (223.0197)<br>27<br>677<br>–<br>0.7<br>–<br>[Rn]7s¹<br>**87**<br>**Fr**<br>Francium | (226.0254)<br>700<br><1140<br>5.0<br>0.9<br>5.279<br>[Rn]7s²<br>**88**<br>**Ra**<br>Radium | (227.0278)<br>1051<br>3198<br>10.07<br>1.1<br>6.5<br>[Rn]6d¹7s²<br>**89**<br>**Ac**<br>Actinium | (261.11)<br>–<br>–<br>–<br>–<br>–<br>[Rn]5f¹⁴6d³7s²<br>**104**<br>**Unq**<br>Unnilquadium | (262.114)<br>–<br>–<br>–<br>–<br>–<br>[Rn]5f¹⁴6d⁴7s²<br>**105**<br>**Unp**<br>Unnilpentium | (263.118)<br>–<br>–<br>–<br>–<br>–<br>[Rn]5f¹⁴6d⁵7s²<br>**106**<br>**Unh**<br>Unnilhexium | (262.12)<br>–<br>–<br>–<br>–<br>–<br>[Rn]5f¹⁴6d⁶7s²<br>**107**<br>**Uns**<br>Unnilseptium | (265)<br>–<br>–<br>–<br>–<br>–<br>[Rn]5f¹⁴6d⁷7s²<br>**108**<br>**Uno**<br>Unniloctium | (266)<br>–<br>–<br>–<br>–<br>–<br>[Rn]5f¹⁴6d⁸7s²<br>**109**<br>**Une**<br>Unnilennium | (272)<br>–<br>–<br>–<br>–<br>–<br>[Rn]5f¹⁴6d¹⁰7s¹<br>**110**<br>**Uum**<br>Ununnium | | | | | | | |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
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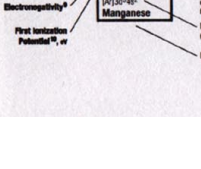
| 140.115<br>799<br>3424<br>6.770<br>1.12<br>5.466<br>[Xe]4f¹5d¹6s²<br>**58**<br>**Ce**<br>Cerium | 140.90765<br>931<br>3510<br>6.773<br>1.13<br>5.422<br>[Xe]4f³6s²<br>**59**<br>**Pr**<br>Praseodymium | 144.24<br>1016<br>3056<br>7.00<br>1.14<br>5.489<br>[Xe]4f⁴6s²<br>**60**<br>**Nd**<br>Neodymium | (144.9127)<br>1042<br>3000<br>7.264<br>1.13<br>5.554<br>[Xe]4f⁵6s²<br>**61**<br>**Pm**<br>Promethium | 150.36<br>1072<br>1794<br>7.536<br>1.17<br>5.631<br>[Xe]4f⁶6s²<br>**62**<br>**Sm**<br>Samarium | 151.965<br>822<br>1596<br>5.244<br>1.2<br>5.666<br>[Xe]4f⁷6s²<br>**63**<br>**Eu**<br>Europium | 157.25<br>1314<br>3264<br>7.901<br>1.20<br>6.141<br>[Xe]4f⁷5d¹6s²<br>**64**<br>**Gd**<br>Gadolinium | 158.92534<br>1359<br>3201<br>8.230<br>1.2<br>5.852<br>[Xe]4f⁹6s²<br>**65**<br>**Tb**<br>Terbium | 162.50<br>1411<br>2567<br>8.551<br>1.22<br>5.927<br>[Xe]4f¹⁰6s²<br>**66**<br>**Dy**<br>Dysprosium | 164.93032<br>1472<br>2694<br>8.80<br>1.23<br>6.015<br>[Xe]4f¹¹6s²<br>**67**<br>**Ho**<br>Holmium | 167.26<br>1529<br>2802<br>9.066<br>1.24<br>6.101<br>[Xe]4f¹²6s²<br>**68**<br>**Er**<br>Erbium | 168.93421<br>1545<br>1946<br>9.321<br>1.25<br>6.18436<br>[Xe]4f¹³6s²<br>**69**<br>**Tm**<br>Thulium | 173.04<br>824<br>1194<br>6.966<br>1.1<br>6.25394<br>[Xe]4f¹⁴6s²<br>**70**<br>**Yb**<br>Ytterbium | 174.967<br>1663<br>3393<br>9.84<br>1.27<br>5.42589<br>[Xe]4f¹⁴5d¹6s²<br>**71**<br>**Lu**<br>Lutetium |
| 232.0381<br>1750<br>4788<br>11.72<br>1.3<br>6.08<br>[Rn]6d²7s²<br>**90**<br>**Th**<br>Thorium | 231.03588<br>1572<br>–<br>15.37<br>1.5<br>5.89<br>[Rn]5f²6d¹7s²<br>**91**<br>**Pa**<br>Protactinium | 238.0289<br>1135<br>4131<br>19.05 α 0.02<br>1.38<br>6.19<br>[Rn]5f³6d¹7s²<br>**92**<br>**U**<br>Uranium | (237.0482)<br>644<br>3902<br>20.45<br>1.36<br>6.19<br>[Rn]5f⁴6d¹7s²<br>**93**<br>**Np**<br>Neptunium | (244.0642)<br>640<br>3232<br>19.816<br>1.28<br>6.06<br>[Rn]5f⁶7s²<br>**94**<br>**Pu**<br>Plutonium | (243.0614)<br>1176<br>2607<br>13.67<br>1.3<br>5.993<br>[Rn]5f⁷7s²<br>**95**<br>**Am**<br>Americium | (247.0703)<br>1345<br>–<br>13.51<br>1.3<br>6.02<br>[Rn]5f⁷6d¹7s²<br>**96**<br>**Cm**<br>Curium | (247.0703)<br>1050<br>–<br>14.78<br>1.3<br>6.23<br>[Rn]5f⁹7s²<br>**97**<br>**Bk**<br>Berkelium | (251.0796)<br>900<br>–<br>–<br>1.3<br>6.30<br>[Rn]5f¹⁰7s²<br>**98**<br>**Cf**<br>Californium | (252.083)<br>860<br>–<br>–<br>1.3<br>6.42<br>[Rn]5f¹¹7s²<br>**99**<br>**Es**<br>Einsteinium | (257.0951)<br>1527<br>–<br>–<br>1.3<br>6.50<br>[Rn]5f¹²7s²<br>**100**<br>**Fm**<br>Fermium | (258.10)<br>827<br>–<br>–<br>1.3<br>6.58<br>[Rn]5f¹³7s²<br>**101**<br>**Md**<br>Mendelevium | (259.1009)<br>827<br>–<br>–<br>1.3<br>6.65<br>[Rn]5f¹⁴7s²<br>**102**<br>**No**<br>Nobelium | (262.11)<br>1627<br>–<br>–<br>–<br>–<br>[Rn]5f¹⁴6d¹7s²<br>**103**<br>**Lr**<br>Lawrencium |

*indicates approximate values and/or inconsistent literature data.

The data for this reference guide were obtained from the latest scientific and government sources (IUPAC, CODATA, National Bureau of Standards, etc.). Unfounded values and/or inconsistent data are marked with an asterisk (*).

1. Ratio of the average mass per atom of the element to 1/12 of the mass of an atom of $^{12}C$. Boxed brackets indicate atomic weight of the most stable or best known isotope. 2. Number of protons in the nucleus of each atom of an element. 3. Number of charge an atom would have in a molecule (or an ionic compound) if electrons were transferred completely. 4. Names and symbols of elements 104-110 are those recommended by the International Union of Pure and Applied Chemistry (IUPAC)—alternative names have been proposed by other groups. 5. Distribution of electrons among the various atomic orbitals. 6. Two older group classifications systems still in use today rely on an A/B coding scheme to categorize periodic properties. Because of the potential for confusion between these two systems (i.e., IVA in one scheme is equal to VIB in the other), IUPAC recommends the use of an unambiguous 1-18 group classification system. 7. Melting point: temperature at which solid and liquid phases coexist in equilibrium. Boiling point: temperature at which the vapor pressure of a liquid is equal to the external atmospheric pressure. Unless otherwise stated values are at 1 atm; SP = sublimation point at 1 atm; TP = triple point. 8. Mass of the substance divided by its volume (g/cm³ at 20°C for gases; g/L at 0°C, 1 atm). 9. Relative measure of the attraction of an atom in a chemical bond for the shared electrons. 10. Minimum energy to remove an electron from an isolated atom in its ground state (1eV = 96.487 kJ/mol).





PAPERTECH

**Editors:** T. K. Varga, M.A.Sc. & C. Bello, M.A.Sc.

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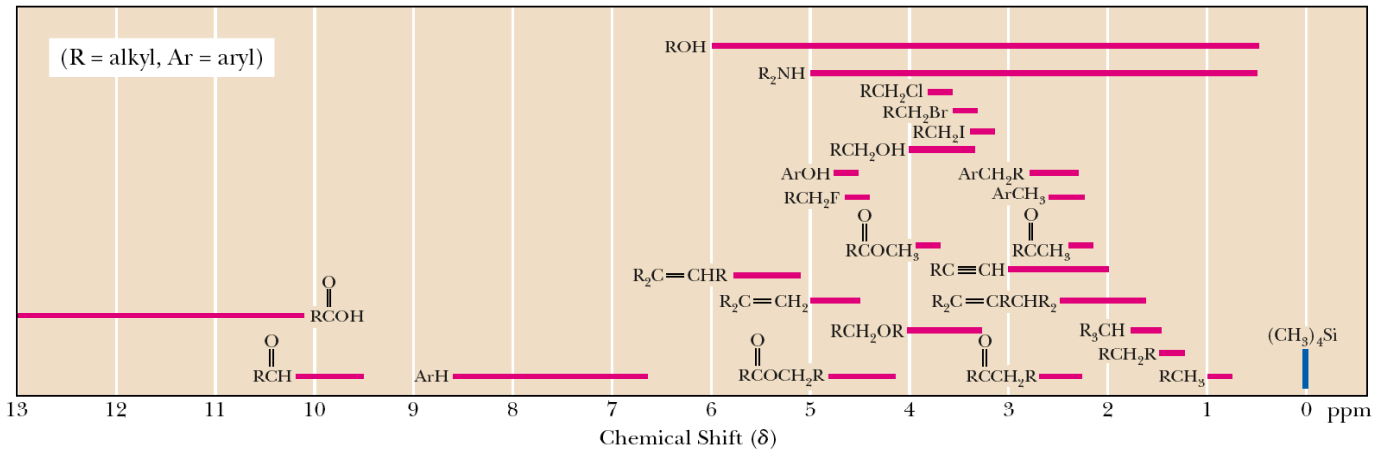
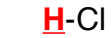
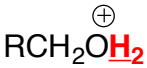
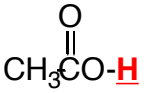
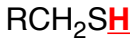
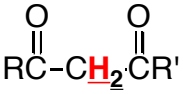
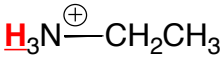
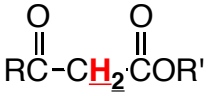
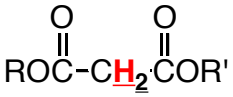
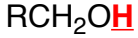
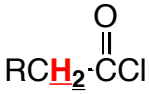
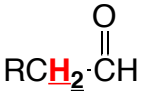
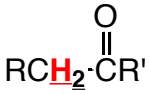
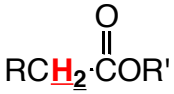
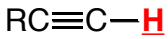
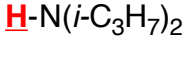
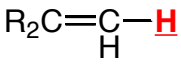
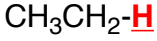
| Type of Hydrogen (R = alkyl, Ar = aryl) | Chemical Shift (δ)* | Type of Hydrogen (R = alkyl, Ar = aryl) | Chemical Shift (δ)* |
|---|---|---|---|
| | | $RCH_2OH$ | 3.4-4.0 |
| $R_2NH$ | 0.5-5.0 | $RCH_2Br$ | 3.4-3.6 |
| $ROH$ | 0.5-6.0 | $RCH_2Cl$ | 3.6-3.8 |
| $RCH_3$ | 0.8-1.0 | $RCOCH_3$ | 3.7-3.9 |
| $RCH_2R$ | 1.2-1.4 | $RCOCH_2R$ | 4.1-4.7 |
| $R_3CH$ | 1.4-1.7 | $RCH_2F$ | 4.4-4.5 |
| $R_2C{=}CRCHR_2$ | 1.6-2.6 | $ArOH$ | 4.5-4.7 |
| $RC{\equiv}CH$ | 2.0-3.0 | $R_2C{=}CH_2$ | 4.6-5.0 |
| $RCCH_3$ | 2.1-2.3 | $R_2C{=}CHR$ | 5.0-5.7 |
| $RCCH_2R$ | 2.2-2.6 | $H_2C(O)CH_2$ | 3.3-4.0 |
| $ArCH_3$ | 2.2-2.5 | $RCH$ | 9.5-10.1 |
| $RCH_2NR_2$ | 2.3-2.8 | $RCOH$ | 10-13 |
| $RCH_2I$ | 3.1-3.3 | | |
| $RCH_2OR$ | 3.3-4.0 | | |

*Values are relative to tetramethylsilane. Other atoms within the molecule may cause the signal to appear outside these ranges.

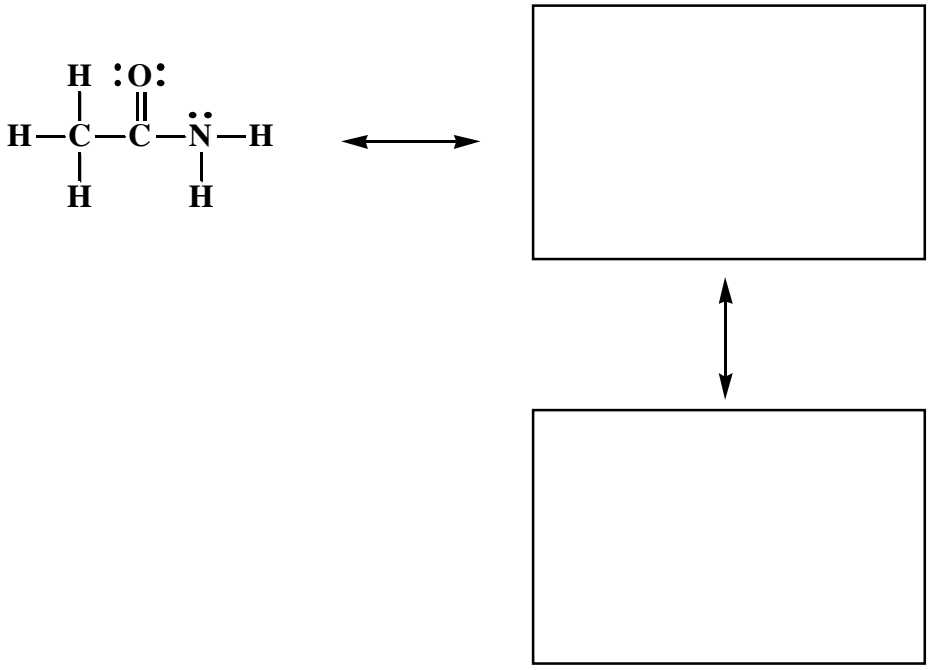


| Compound | | $pK_a$ |
|---|---|---|
| Hydrochloric acid |  | -7 |
| Protonated alcohol |  | -2 |
| Hydronium ion | | -1.7 |
| Acetic acid |  | 4.8 |
| Ammonium ion | | 9.2 |
| Thiols |  | 10-12 |
| β-Dicarbonyls |  | 10 |
| Ethyl ammonium ion |  | 10.8 |
| β-Ketoesters |  | 11 |
| β-Diesters |  | 13 |
| Water | | 15.7 |
| Alcohols |  | 15-19 |
| Acid chlorides |  | 16 |
| Aldehydes |  | 18-20 |
| Ketones |  | 18-20 |
| Esters |  | 23-25 |
| Terminal alkynes |  | 25 |
| LDA |  | 40 |
| Terminal alkenes |  | 44 |
| Alkanes |  | 51 |

**Signature**_____ Pg 1 _____(29)

**1.** (5 pts) What is the most important question in organic chemistry?

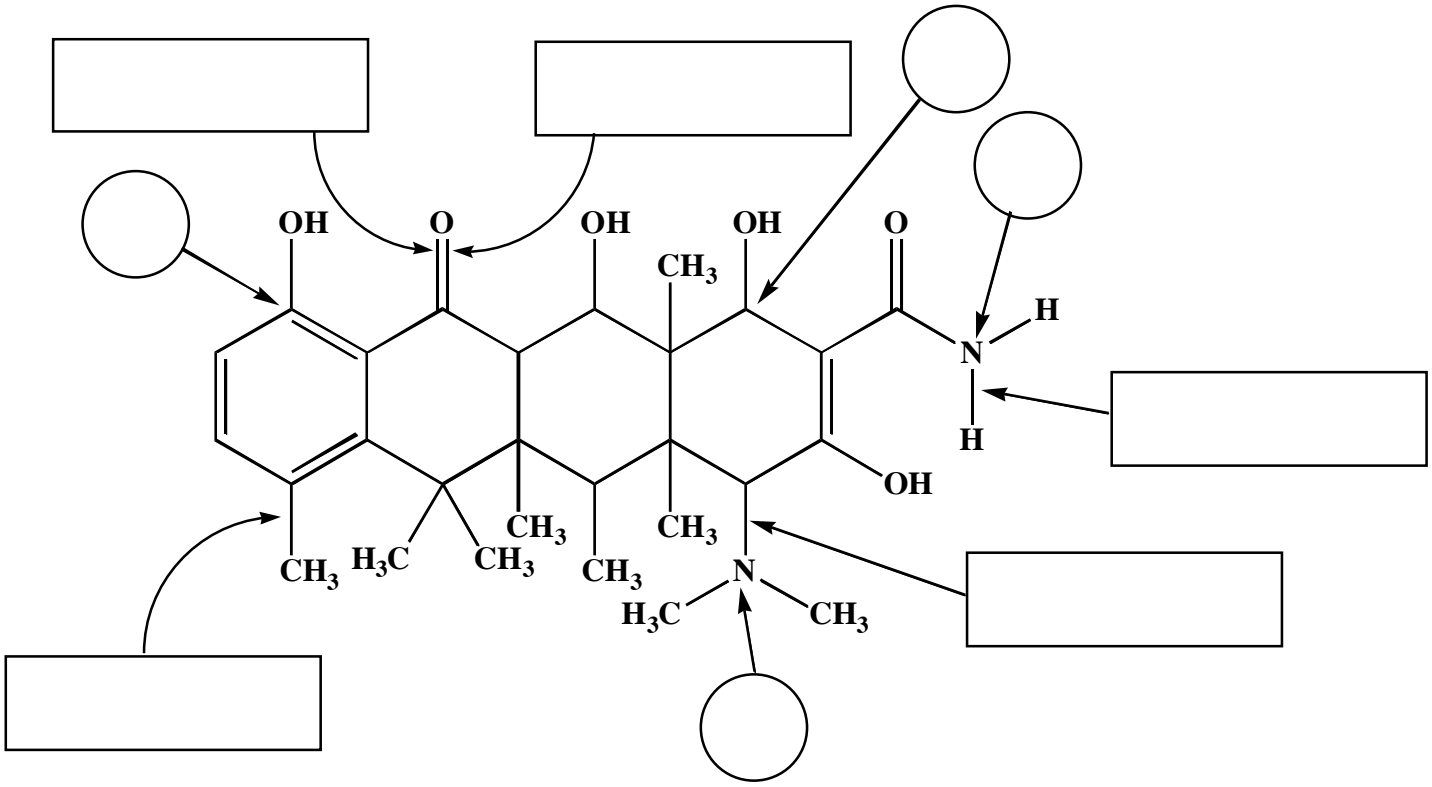
**2.** (10 pts) Amides are best represented as the hybrid of three contributing structures. Draw the second and third important contributing structures in the spaces provided, including all lone pairs and formal charges. For the two structures on the left in each problem, use arrows to indicate the movement of electrons to give the structures you drew. There is no need to draw any circles around any of these contributing strucures. You might want to read these directions again to make sure you know what we want



**3.** (14 points) Suppose a relative of yours is having an MRI. In no more than four sentences, explain to them what is happening when they have the MRI scan. We will be looking for a minumum of 7 key points here and your answer should match a recent Rule of the Day.

**4.** (1 pts each) Below is the structure of the antibiotic tetracycline. **In the rectangles provided, indicate the type of bond** and the hybridized orbitals that overlap to form the bond. For example, one answer could be: $\sigma_{Csp^3\text{-}H1s}$

**Next, in the circles provided, write the hybridization state of the atoms indicated with the arrows.**




**5.** (1 pt each) On the above structure of tetraycline, the stereochemistry is not indicated. On the above structure indicate **EACH CHIRAL CENTER WITH AN ASTERISK (*).**

**6.** (5 pts). Tetracycline is sold as a single stereoisomer. How many possible stereoisomers are there for tetracycline? It is OK to leave your answer in the form of an exponential. No need to multiply it out.

_____

**7.** (1 pt each) **Circle all the True statements.** (Do not circle any false statements) You may notice these resemble Rules of the Day! These are worth a significant number of points, so read them carefully and do not second guess yourself. We are not trying to trick you into the wrong answer.

**A.** For organic chemistry, it is best to think of electron density as particles, described by particle equations such as Kepler's laws of motion, which were recently passed as part of the economic bailout legislation.

**B.** For organic chemistry, it is best to think of electron density as waves, described by wave equations (NOT discrete particles orbiting the nucleus!)

**C.** The preferred staggered conformation of butane is referred to as "gotcha", rather than the "anti" or "eclipsed" conformation.

**D.** Diastereomers are stereoisomers that are not enantiomers.

**E.** There is an absolute link between "R" and "S", "D" and "L" and "+" and "-", because "R" is always "D" and "+" , while "S" is always "L" and "-".

**F.** Substituted cyclohexanes prefer (i.e. are lower in energy) to have as many substituents in equatorial positions as possible, with the larger substituents dominating.

**G.** Samples of enantiomers rotate the plane of plane polarized light to an equal extent, but in opposite directions.

**H.** Anti stereochemistry of addition means that the atoms add to either side of a C=C double bond, syn means they add to the same side, and mixed means they add both syn and anti in the same reaction.

**I.** Bulky groups (who obviously used performance enhancing steroids) on the back of an alkyl halide increase non-bonded interaction strain, and thereby accelerate an $S_N2$ reaction.

**J.** Because of the electron density of the pi bond, alkenes react as nucleophiles to make new bonds with molecules containing high partial positive charge (electrophiles).

**K.** If electromagnetic energy of the precise energy diffence between the +1/2 and -1/2 spins states is used to irradiate the sample, the energy is absorbed as the spin "flips" from the +1/2 state to the -1/2 state.

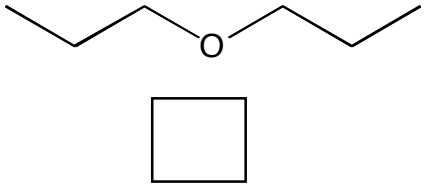
**L.** A $^1H$ nucleus surrounded by greater electron density is considered to be more shielded and comes into resonance (absorbs electromgnetic radiation) at a higher frequency (larger ppm).

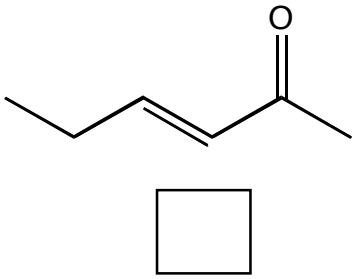
**M.** A $^1H$ nucleus surrounded by greater electron density is considered to be more shielded and comes into resonance (absorbs electromgnetic radiation) at a lower frequency (smaller ppm).

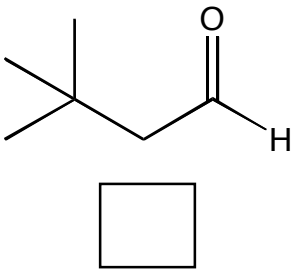
**N.** "Resonance" in NMR refers to the phenomenon of absorption of energy when a nuclear spin "flips".

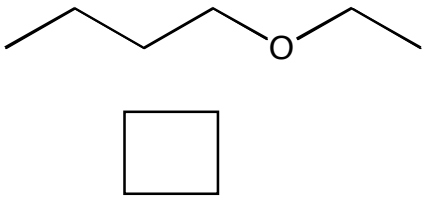
**O.** Running 3-5 miles a week EVERY WEEK as an adult dramatically increases your fitness level and improves your heatlh throughout your life. Doing this and enjoying a healthy life is even more important than getting an A on this organic final!

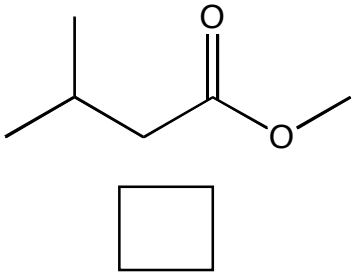
**8.** (15 pts total) On the following three pages there are NMR spectra. The relative integrations are given above each signal. Assign each spectra to the appropriate structure out of the following possibilities. Each NMR spectrum has a letter on it. **Write the appropriate letter underneath the molecules in the space provided.** Notice that not all of the molecules below will have letters underneath them, as there are only three spectra but seven molecules.

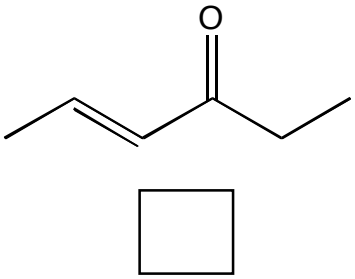


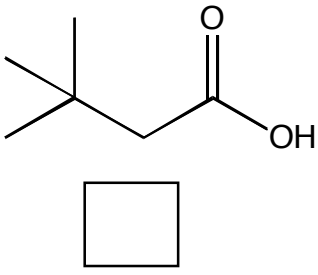



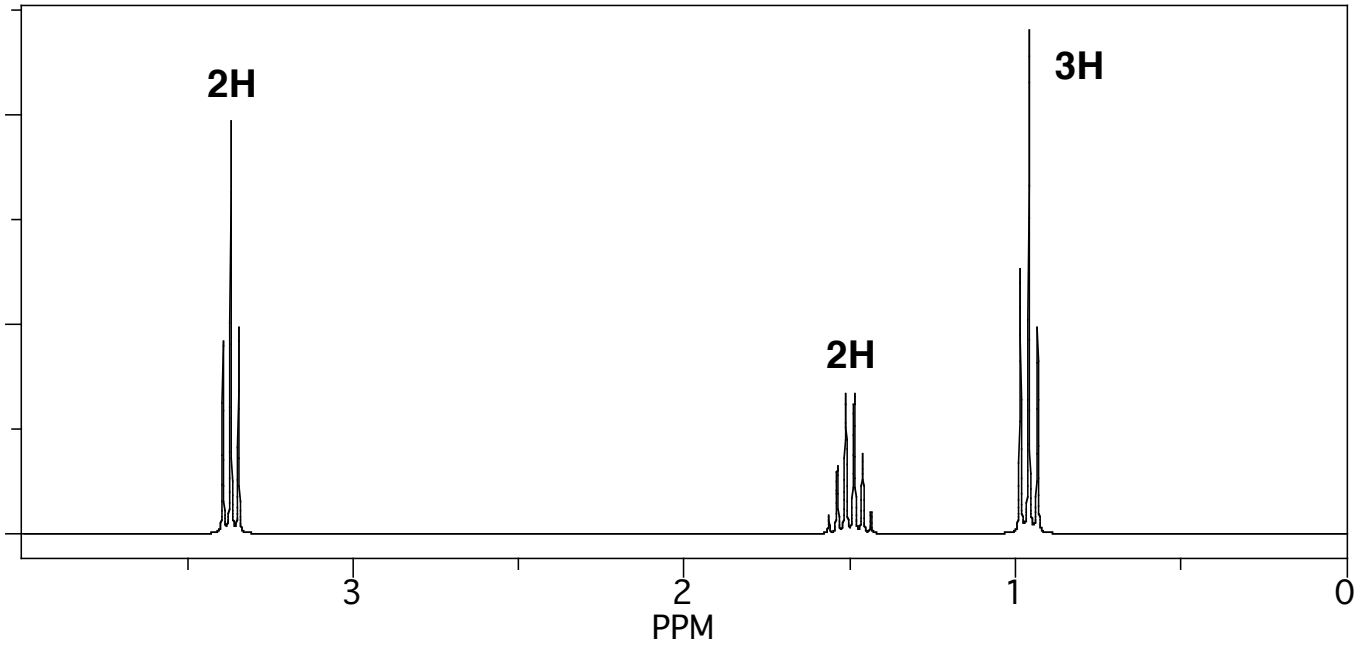



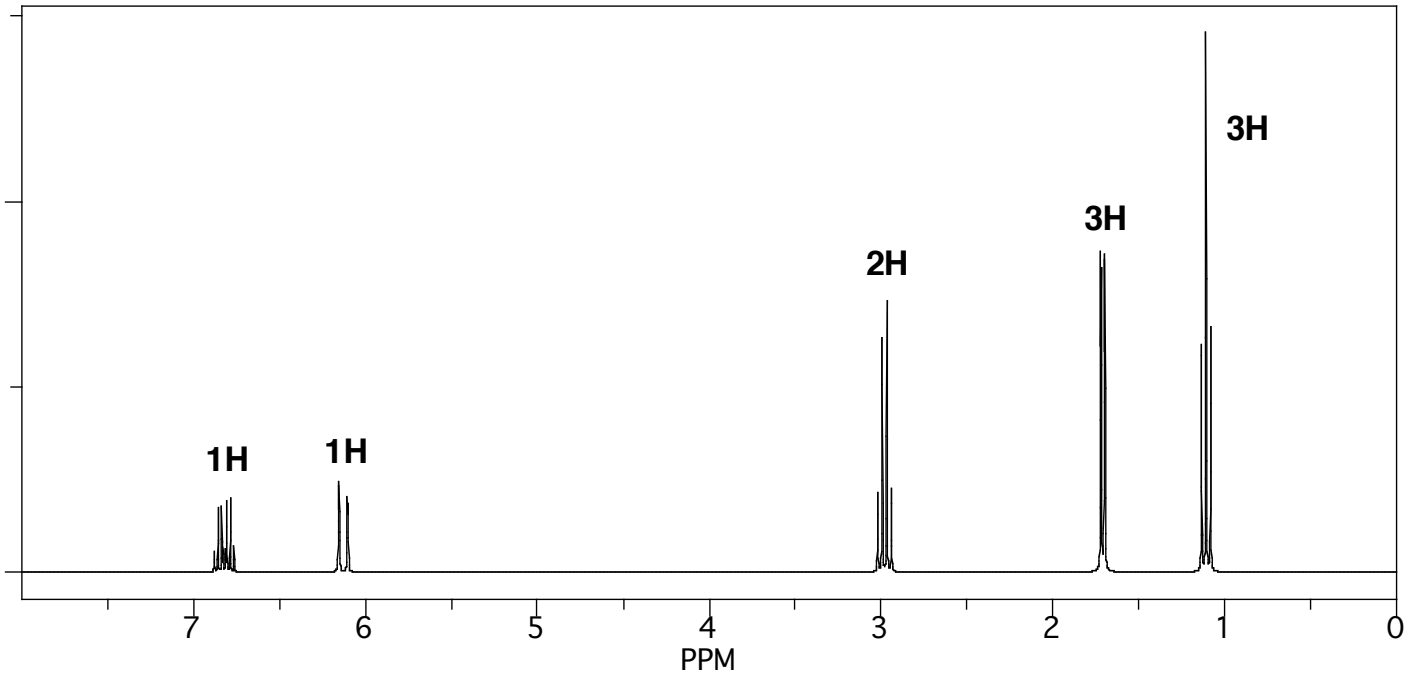



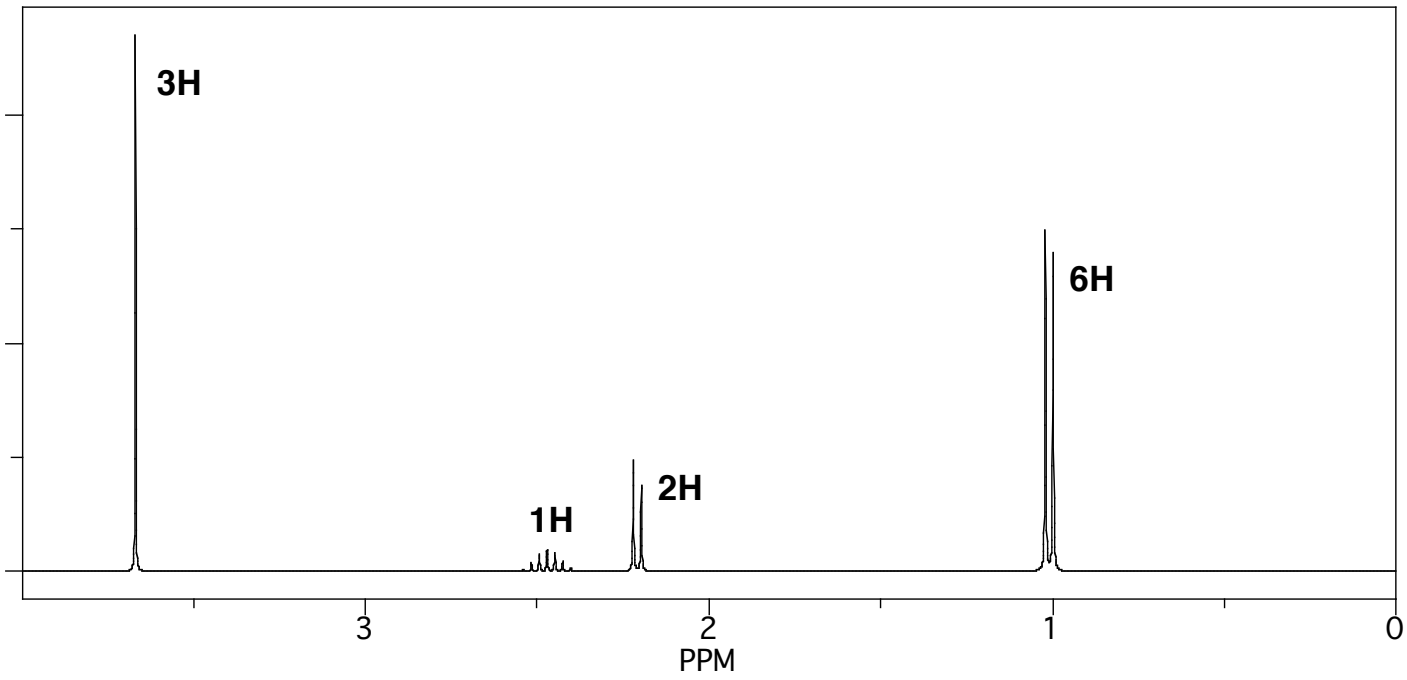
# A



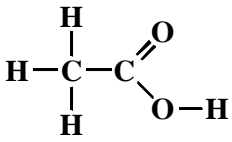
# B

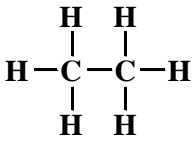


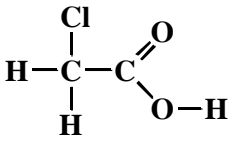
# C

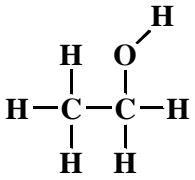


**9.** (4 pts) Rank the following with respect to relative acidity. Put a **1** under the molecule that is **most acidic**, and a **4** under the molecule that is **least acidic**. Remember, the **1 goes under the MOST acidic!**



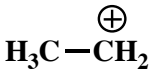


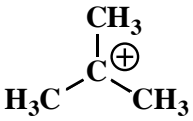


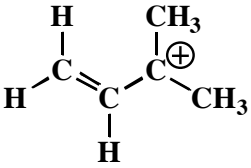


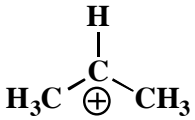
**relative rank:** _____ _____ _____ _____

**10.** (4 pts total) For the following series of compounds, rank them in order of most to least stable cation by writing a **1** under the **most stable** all the way to a **4** under the **least stable.**



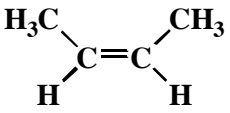


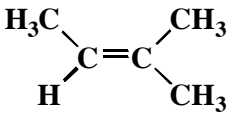


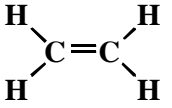


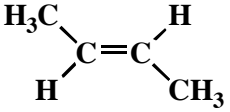
**relative rank:** _____ _____ _____ _____

**11.** (4 pts) **Stability of alkenes:** Place a **1** under the most stable (i.e. most favored Zaitzev product) and a **4** under the least stable (least stable Zaitzev product) alkene



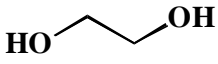


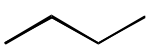


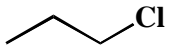


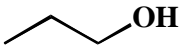
**relative rank:** _____ _____ _____ _____

**12.** (4 pts total) For the following compounds, rank them in order of highest to lowest boiling point, with a **1 under the molecule with the highest boiling point** and a **4 under the molecule with the lowest boiling point**.





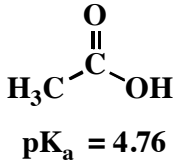




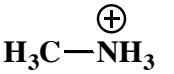
**relative rank:** _____ _____ _____ _____

*Are you sure you ranked them in the correct order according to the directions????*

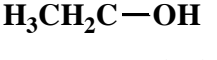
**13.** (7 pts) **Complete the following structure by adding appropriate numbers of lone pair electrons, H atoms, and formal charges to the atoms in the boxes.** You must adjust your answers to indicate the predominant species at pH 2. This problem is testing your understanding of the relationship of protonation state to pH to pKa values for certain functional groups we have discussed. **Next, in the space provided, write the overall charge on the molecule at pH 2. For your reference, here are the relavant pKa vaules:**



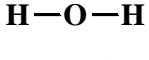

**$pK_a$ = 4.76**




**$pK_a$ = 10.64**

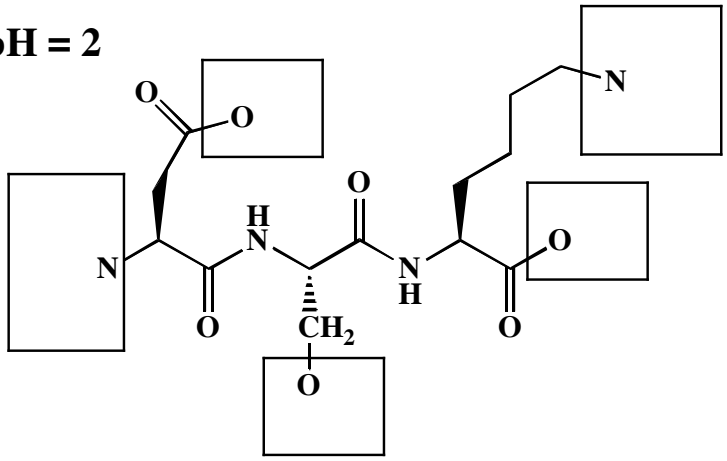



**$pK_a$ = 15.9**



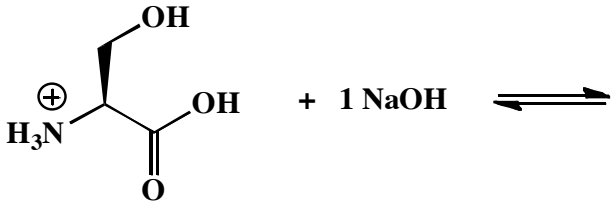

**$pK_a$ = 15.7**

**pH = 2**



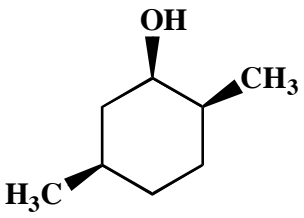

**Total charge on molecule:_____**

**14.** (4 pts) Using the pKa information from above (Problem 13), **draw the predominant form of the following molecule (the amino acid serine)** when it is mixed with exactly one equivalent of NaOH. In other words, when equal numbers of each kind of molecule are mixed.




**+ 1 NaOH** ⇌ **+ $Na^{\oplus}$ + $H_2O$**

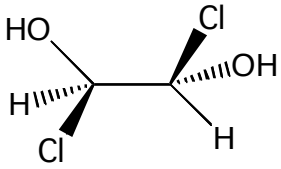
**15.** (8 pts) In the two spaces below, draw the two equilibrating chair structures for the following cyclohexane derivative. **Circle the one that predominates at equilibrium.**

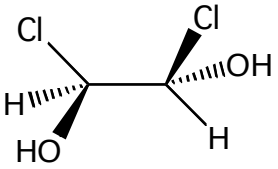



⇌

**16**. (8 pts) On the line provided, state the stereochemical relationship between each pair of molecules: **enantiomers, diastereomers, or the same molecule**. I recommend you assign R and S to each chiral center to help answer this question. **Circle all meso compounds.**

**Relationship**

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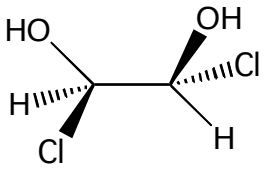
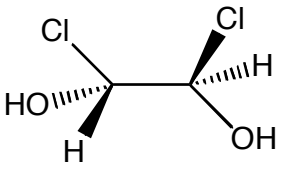
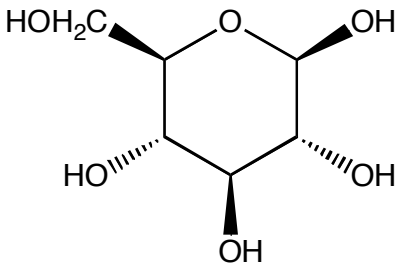
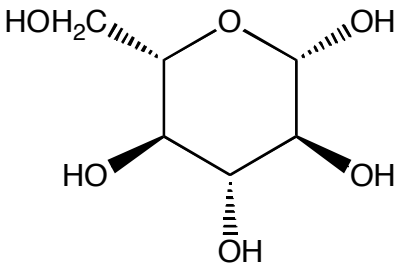


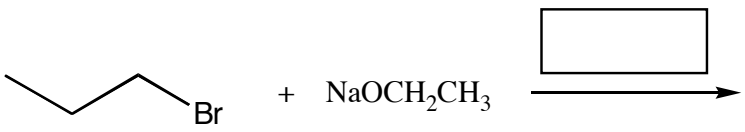

_____

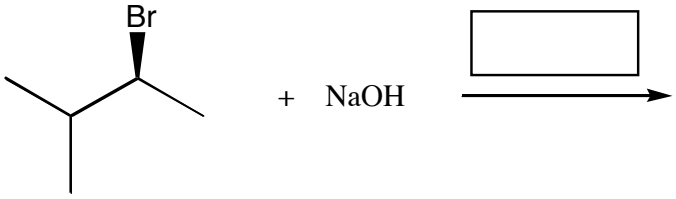


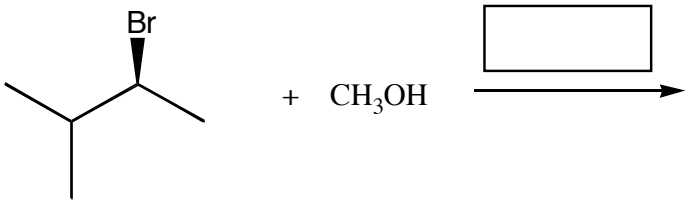




_____

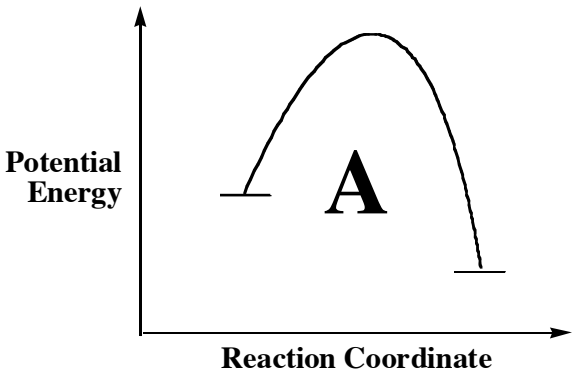
**17.** (13 pts) For the following reactions, draw the predominant product(s), and in the box over the arrow, write the predominant mechanism(s) ($S_N2$, E2 or $S_N1$/E1)

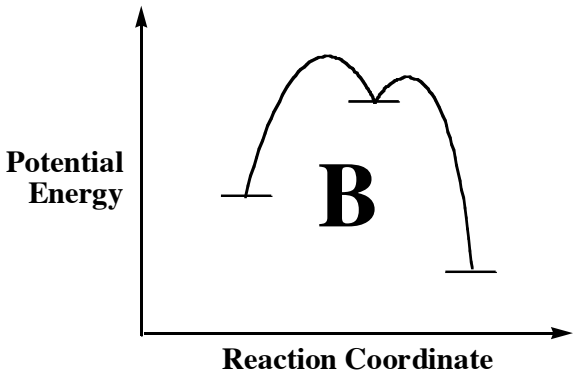


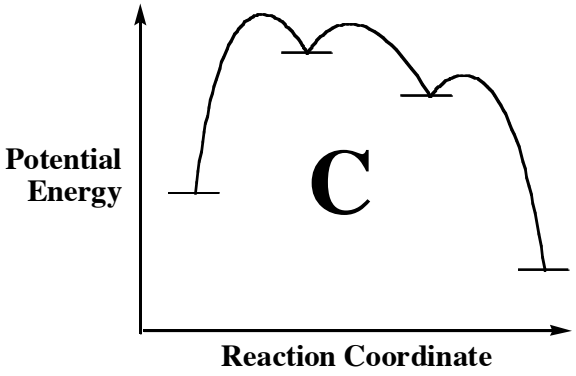



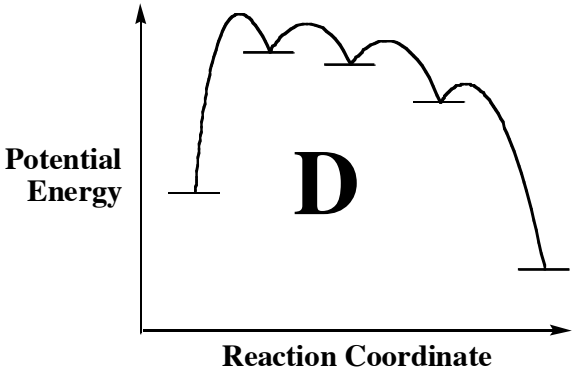



**18.** Shown below are four different energy diagrams. Each is labeled with a letter. **Use these letters to answer questions at the bottom of the next two mechanism questions.**

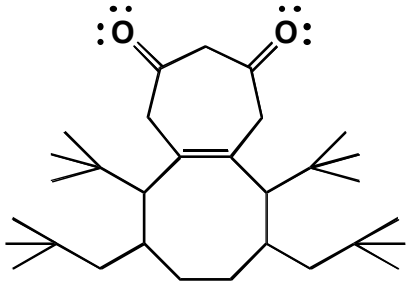


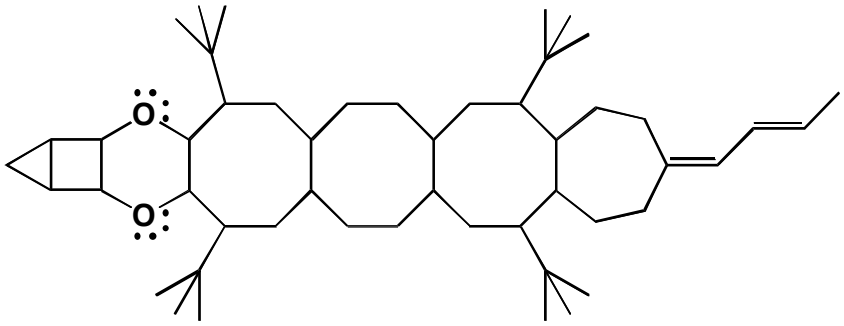



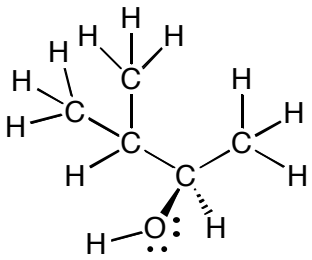



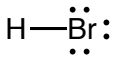

**Molecular amphibians**



**19.** (22 pts.) Read these directions carefully. Read these directions carefully. (It was worth repeating) **For the reaction of this alcohol with HBr, fill in the details of the mechanism. Draw the appropriate chemical structures and use an arrow to show how pairs of electrons are moved to** make and break bonds during the reaction. **For this question, you must draw all molecules produced in each step (yes, these equations need to be balanced!). Finally, fill in the boxes adjacent to the arrows with the type of step involved, such as "Make a bond" or "Take a proton away". MAKE SURE TO NOTICE THE QUESTIONS AT THE BOTTOM. Use wedges and dashes to indicate stereochemistry where appropriate, BUT if an intermediate or product is really a racemic mixture, you only need to draw one enantiomer for this problem (we are making this easier for you).**





**Rearrangement**

Product(s)

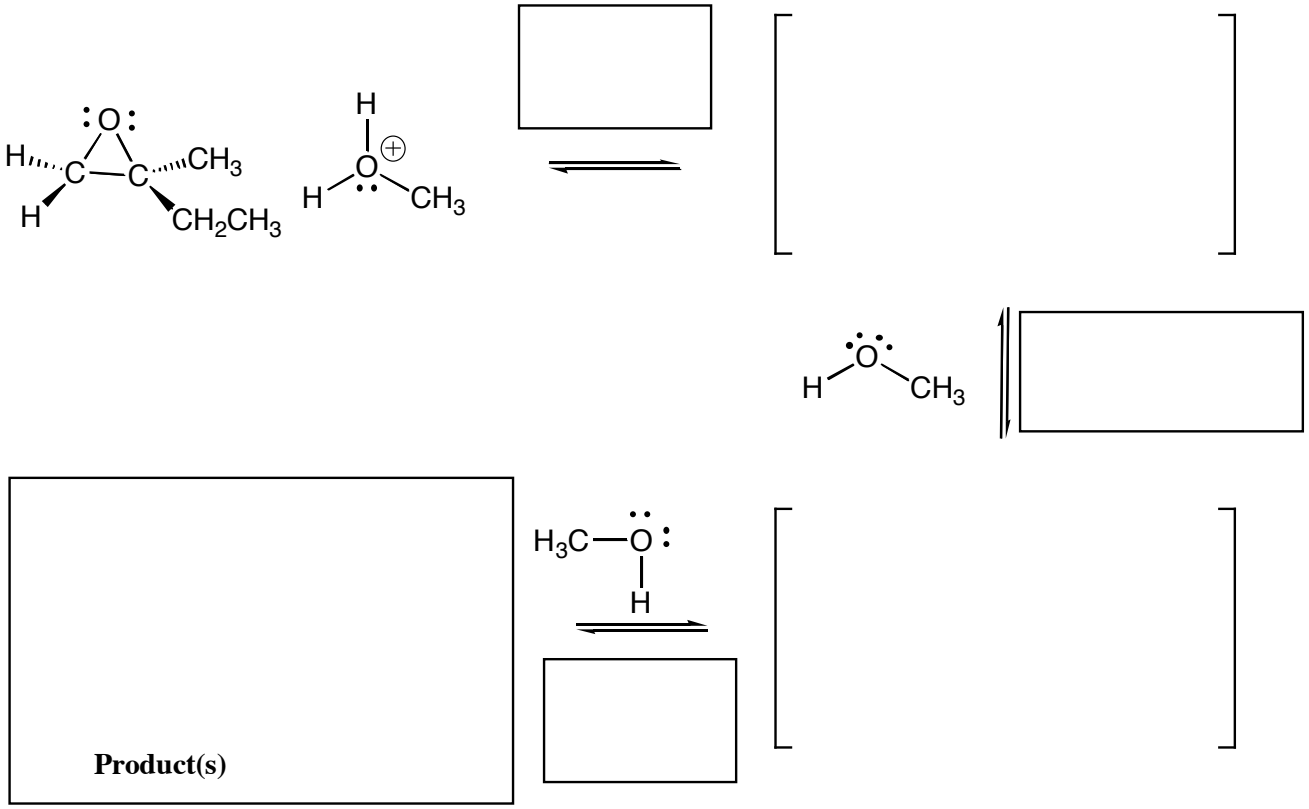
A) Asssuming that 1 equivalent of HBr were used, during the reaction, would the pH rise, fall, or stay the same. In one sentence, explain your answer.

**B)** Of the four energy diagrams listed on the page 11, which one best describes the reaction mechanism you drew:

_____

**NOTICE THESE**

**20.** (25 pts.) **For the reaction of this epoxide with methanol in acid, fill in the details of the mechanism. Draw the appropriate chemical structures and use arrows to show how pairs of electrons are moved to** make and break bonds during the reaction. **For this question, you must draw all molecules produced in each step (yes, these equations need to be balanced!). Finally, fill in the boxes adjacent to the arrows with the type of step involved, such as "Make a bond" or "Take a proton away". MAKE SURE TO NOTICE THE QUESTIONS AT THE BOTTOM. Use wedges and dashes to indicate stereochemistry where appropriate, BUT if an intermediate or product is really a racemic mixture, you only need to draw one enantiomer for this problem (we are making this easier for you).**




A) (2 pts) During the reaction, would the pH rise, fall, or stay the same. In one sentence, explain your answer.

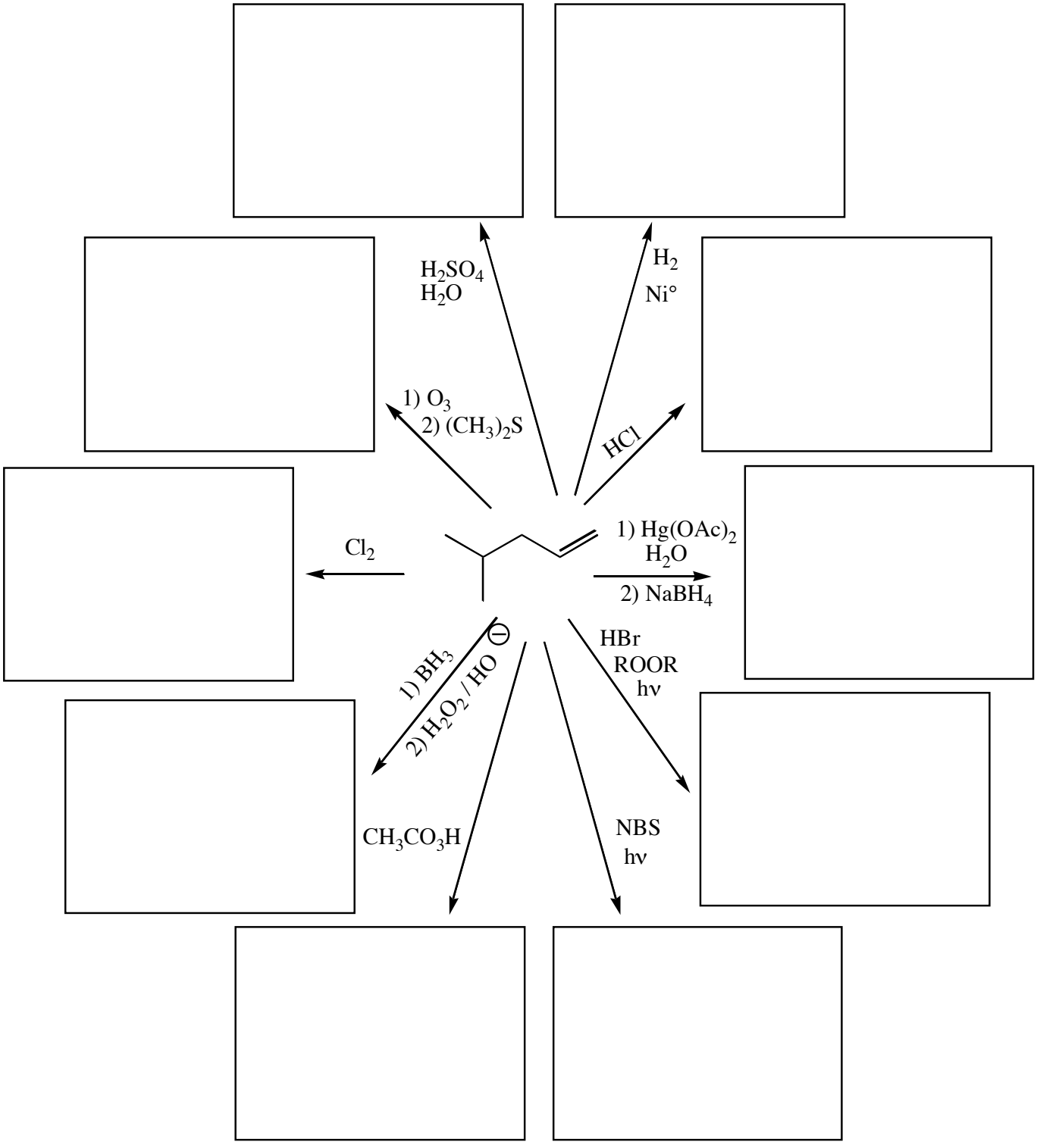
B) (2 pts) Of the four energy diagrams listed on page 11, which one best describes the reaction mechanism you drew:

_____

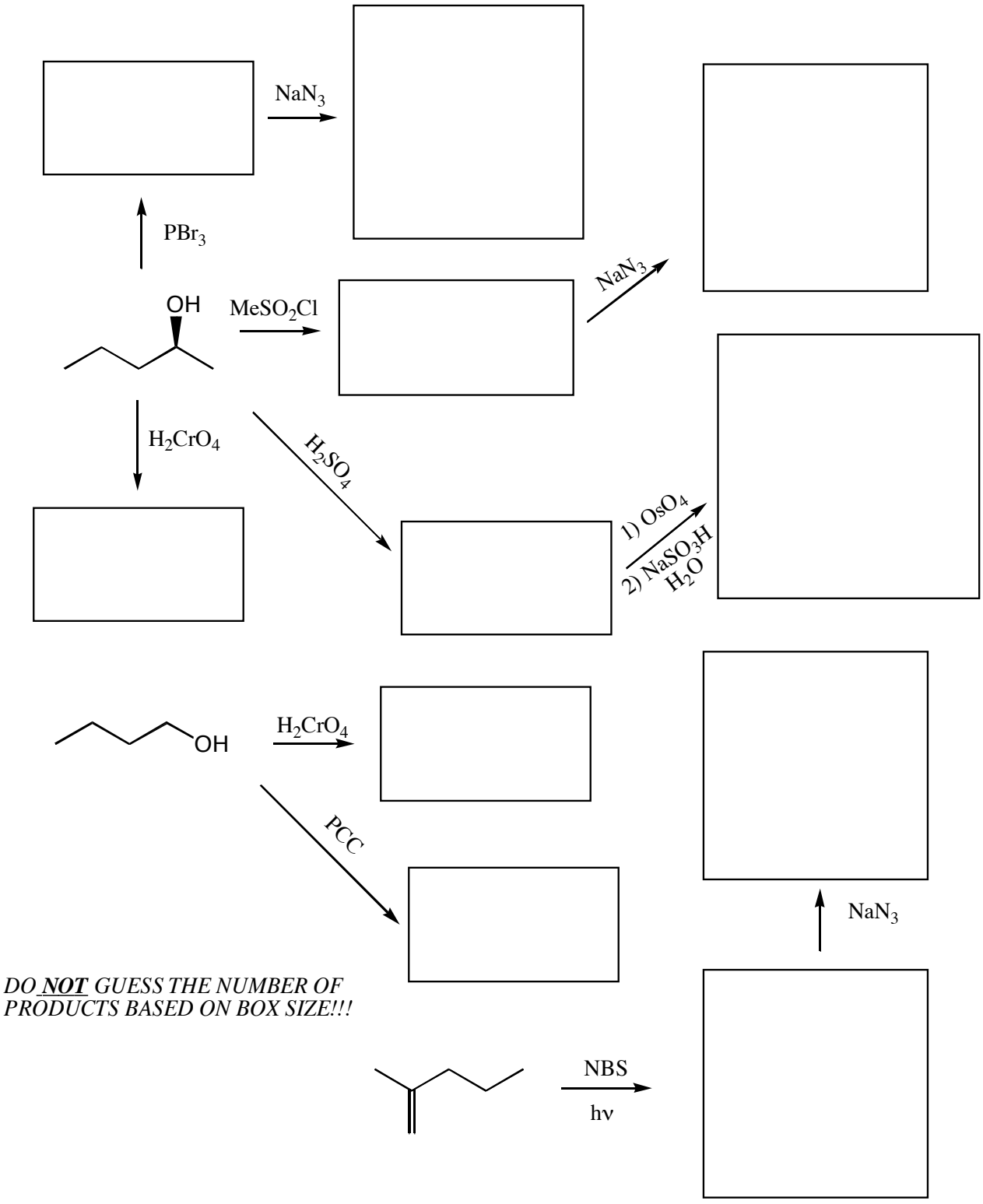
C) (4 pts) **For this part of the question, ignore all proton transfer steps.** For each step that involves a nucleophile reacting with an electrophile, **draw a circle around the nucleophile and a box around the electrophile.**

**NOTICE ALL THREE PARTS OF THIS (A-C)**

**21**. (3 or 5 pts each) For the following, complete the reactions with the predominant product or products. You must indicate stereochemistry with wedges and dashes. You must draw all stereoisomers produced as predominant products and write "racemic" under the structures when appropriate. Assume no rearrangments take place.

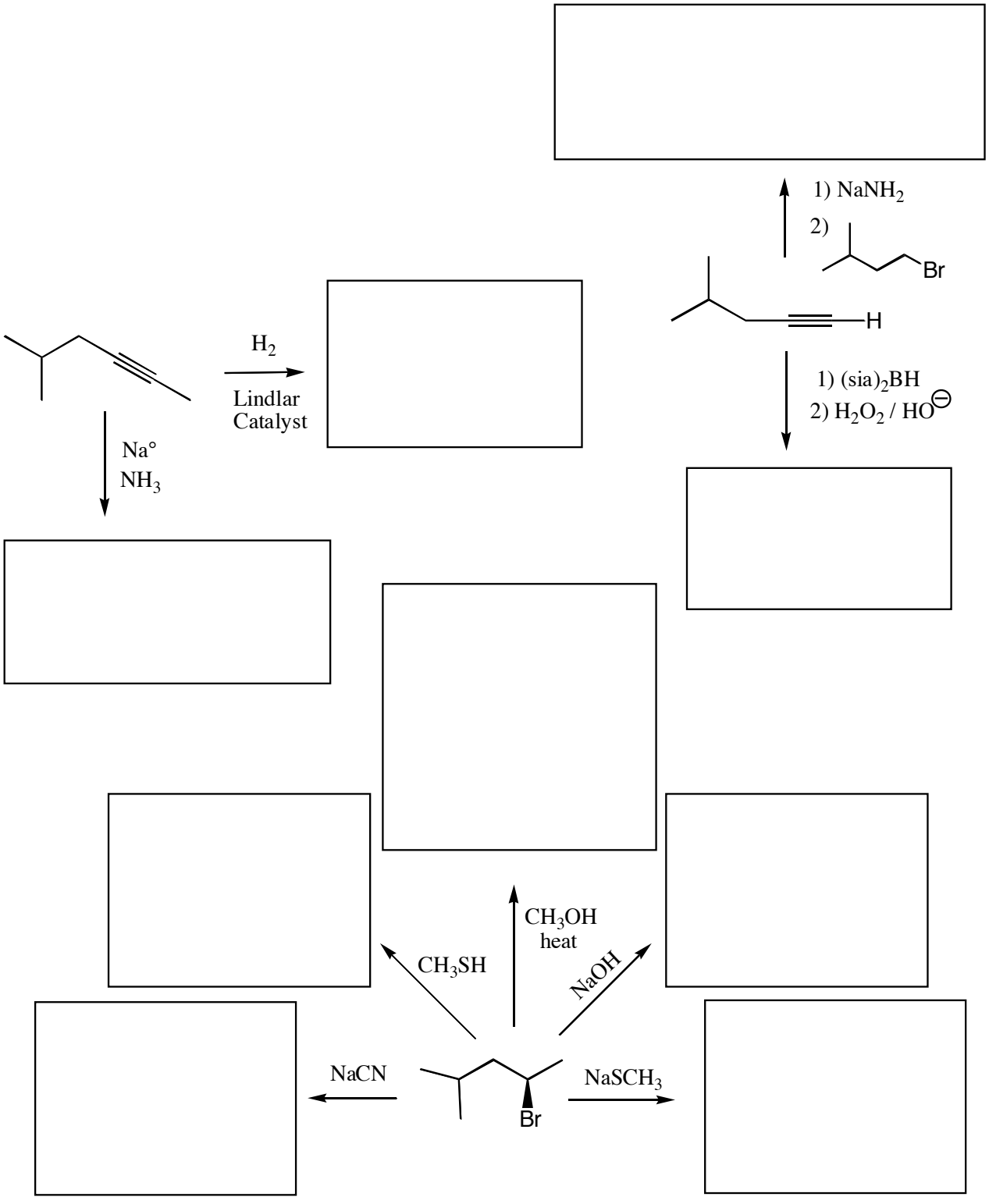


**22**. (3 or 5 pts each) For the following, complete the reactions with the predominant product or products. You must indicate stereochemistry with wedges and dashes. You must draw all stereoisomers produced as predominant products and write "racemic" under the structures when appropriate. Assume no rearrangments take place.



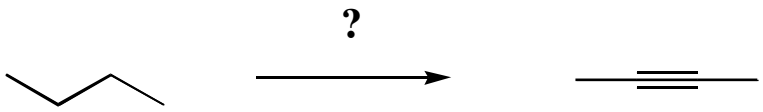

*DO **NOT** GUESS THE NUMBER OF PRODUCTS BASED ON BOX SIZE!!!*

**23**. (3, 5 or 6 pts each) For the following, complete the reactions with the predominant product or products. You must indicate stereochemistry with wedges and dashes. You must draw all stereoisomers produced as predominant products and write "racemic" under the structures when appropriate. Assume no rearrangments take place.

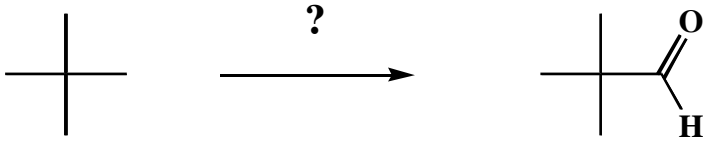


**24.** These are synthesis questions. You need to show how the starting material can be converted into the product(s) shown. You may use any reactions we have learned provided that the product(s) you draw for each step is/are the predominant one(s). Show all the reagents you need. Show each molecule synthesized along the way and be sure to pay attention to the regiochemistry and stereochemistry preferences for each reaction. You must draw all stereoisomers formed, and use wedges and dashes to indicate chirality at each chiral center. Write racemic when appropriate.

A) (10 pts)

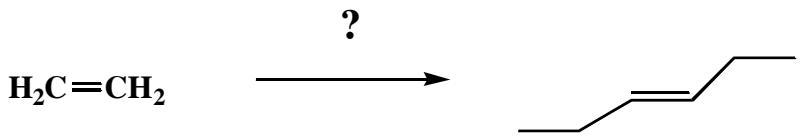



B) (7 pts)



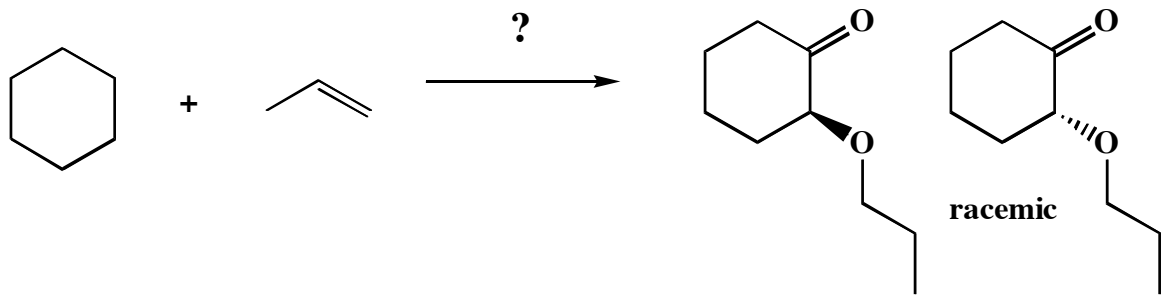
**24** (cont.) These are synthesis questions. You need to show how the starting material can be converted into the product(s) shown. You may use any reactions we have learned provided that the product(s) you draw for each step is/are the predominant one(s). Show all the reagents you need. Show each molecule synthesized along the way and be sure to pay attention to the regiochemistry and stereochemistry preferences for each reaction. You must draw all stereoisomers formed, and use wedges and dashes to indicate chirality at each chiral center. Write racemic when appropriate. **All the carbons of the product must come from carbons of the starting material.**

C) (22 pts)

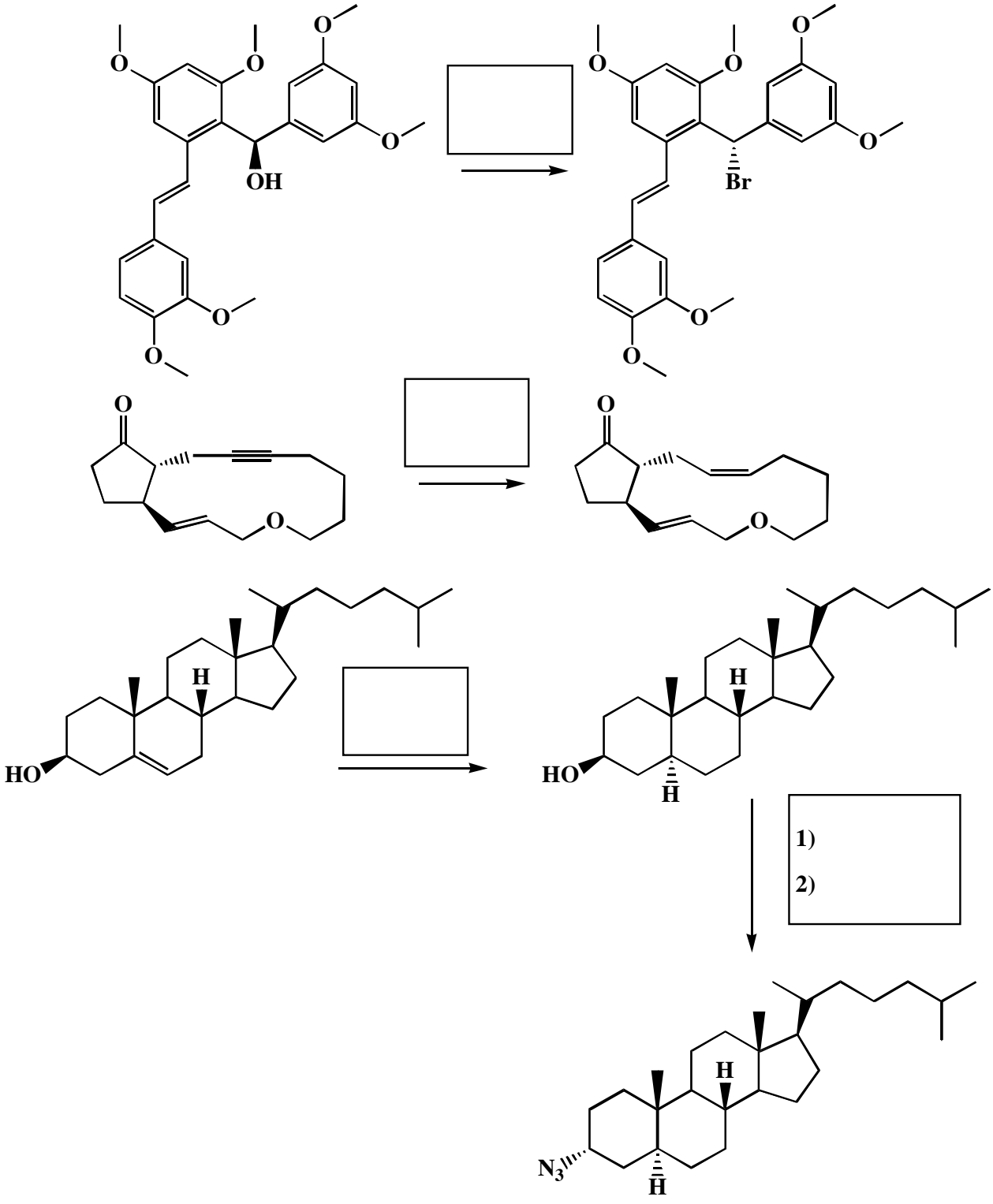


**24** (cont).) These are synthesis questions. You need to show how the starting material can be converted into the product(s) shown. You may use any reactions we have learned provided that the product(s) you draw for each step is/are the predominant one(s). Show all the reagents you need. Show each molecule synthesized along the way and be sure to pay attention to the regiochemistry and stereochemistry preferences for each reaction. You must draw all stereoisomers formed, and use wedges and dashes to indicate chirality at each chiral center. Write racemic when appropriate. **All the carbons of the product must come from carbons of the starting material.**

D) (16 pts)

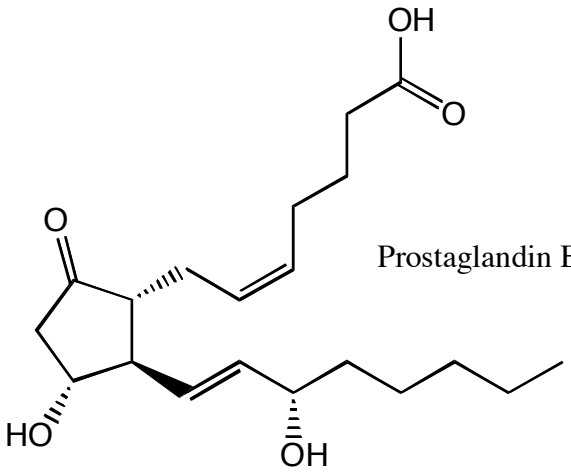


**25.** (12 pts) As we emphasized at the end of the semester, a key paradigm in organic chemistry is that reactions of functional groups work the same in complex molecules as they do in the simpler molecules we usually examine in first semester courses. The following complex molecules and reactions were used in actual syntheses. In the space provided, write the reagents that will produce the transformation shown.



**26**. In reflecting over the semester, it occurs to me that I have not given you ample opportunity to identify functional groups in complex molecules. This is important because, as emphasized on the previous page, the key paradigm in organic chemistry is that a functional group will react the same in complex molecules as it does in simpler ones. For this reason, most textbooks, including ours, is organized around the different functional groups. This semester we have covered the properties and reactions of alkenes, alkynes, haloalkanes, alcohols, thiols, and ethers. We also talked about other functional groups such as aldehydes, ketones, amides and carboxylic acids. It is important that you can recognize these functional groups whenever you encounter them. Below is an important biological molecule and you will be asked to identify functional groups. I have seen similar types of questions on real MCAT exams.

Protaglandins are molecules found in low concentration in the bloodstream, but they regulate important complex functions such as smooth muscle contraction and blood pressure. Following is the structure of a prostaglandin named prostaglandin E2 (PGE2)




Prostaglandin E2 (PGE2)

For the following multiple choice questions, circle the correct answer.

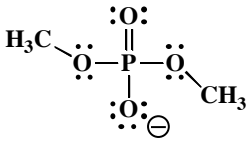
Circle the answer that best describes the functional groups in prostaglandin E2

A) Three alcohol groups, two ketones and two alkenes
B) Two alcohol groups, a ketone, a carboxylic acid and two alkenes
C) Three alcohols, an aldehyde, a ketone and two alkenes
D) Three alcohols, a ketone and a partridge in a pear tree.

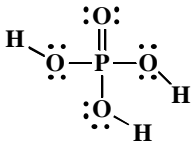
How many total stereoisomers are possible for the prostaglandin E2 core structure?

A) $2^4$
B) $2^5$
C) $2^6$
D) $2^7$

**27.** Every once in a great while a discovery comes along that changes how chemists think about chemical structure. Such an event occurred over the past decade in which it was determined that our understanding of hybridization in many compounds containing sulfur and phosphorus was previously inaccurate. As a result, most of the chemical literature and textbooks have misleading structures. Phosphorus and sulfur are second row elements, so their bonding was thought to involve d orbitals. For that reason, it is common to see more than four bonds to phosphorus in functional groups such as phosphodiesters (found in the DNA backbone) and even in phosphoric acid.

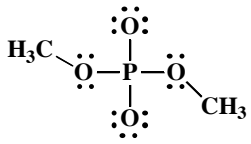


**Phosphodiester**

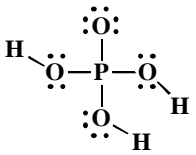


**Phosphoric acid**

Recent calculations have convincingly shown this representation to be incorrect. The d orbitals are not significantly involved in bonding of the phosphorus atom in these molecules. Instead, the phosphorus atom in these molecules is actually $sp^3$ hybridized and only has four single bonds, no double bonds. For the following multiple choice questions, circle the correct answer.

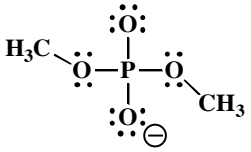


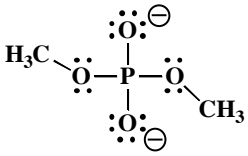
**Phosphodiester**

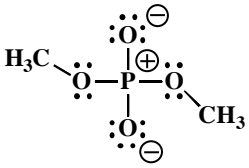


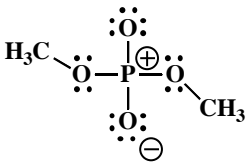
**Phosphoric acid**

Above are drawn structures of a phosphodiester and phosphoric acid with the appropriate hybridization at phosphorus. I intentionally left off the formal charges on the atoms. Which of the following four possibilities best describes the formal charges present on the O and P atoms of the phosphodiester assuming $sp^3$ hybridization at phosphorus?

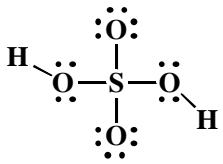
**A)** 

**B)** 

**C)** 

**D)** 

It turns out that the same applies to sufur atom hybrdization in molecules such as sulfuric acid.



**Sulfuric acid**

Assuming that the sulfur atom in sulfuric acid is $sp^3$ hybridized as shown above, what is the formal charge on sulfur?

A) –1 B) neutral (no formal charge) C) +1 D) +2