Department of Chemistry
Cumulative Examinations
May 1, 2010

You may choose to answer any exam from any area covered in the examination booklet. Each exam may contain multiple parts. You may answer more than one exam but each exam is scored separately and is treated as an individual examination result. Thus, answering parts of two exams with a score of 50% *would not* yield a 100% grade for this cumulative exam. Instead you would receive 50% on each examination attempted.

This booklet contains ***five*** examinations.

1) Analytical Cumulative Examination, Pages 1-3
2) Biochemistry Cumulative Examination, Pages 4-6
3) Inorganic Cumulative Examination, Pages 7-8
4) Organic Cumulative Examination, Pages 9-11
5) Physical Cumulative Examination, Pages 12-13

On your examination booklet:

1) Print your student ID number.
2) Print the Exam Booklet number.
3) Print the question number you are answering.
4) Print the Exam Date.

Do not write your name anywhere on the examination booklet. Each exam will be scored anonymously. If you attempt more than one exam, *you must use a separate examination booklet for each examination*.

When you complete the examination, return the examination and your answer booklet to the proctor. Exam results will be posted on bulletin board #2B on the north side of the hall near BRWN 2124.

PURDUE
UNIVERSITY

Analytical Chemistry, May 2010

1) (16 points) Chemical compounds often have ionizing groups and their molar absorption coefficient can vary dramatically depending on whether a group is ionized or not. Assume you have such a compound which you normally assay in the spectrophotometer at pH 8.0. Your spectrophotometer reading is 0.84 at pH 8.0. It has a group that can be protonated with pK_a of 6.0. At pH 4.0 the same spectrophotometer reading is 0.26. What would the absorbance reading be at pH 6.0? You need to show your calculation for your answer.

2) (16 points) In the laboratory there are four different ion-exchange columns whose stationary phases are functionalized with the following groups:

(A) $-SO_3^- H^+$

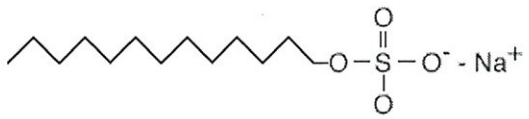
(B) $-COO^- H^+$

(C) $-NH_2CH_3^+Cl^-$

(D) $-N(CH_3)_3^+ Cl^-$

To separate a mixture of oligonucleotides at a slightly basic condition (pH 8), which column should you choose? Give brief explanation for your choice.

3) (16 points) Sodium dodecyl sulfate (SDS; see below for its chemical structure) is a common detergent used in many chemistry research laboratories.



For example, SDS is used to denature proteins to improve the efficiency of protein digestion. The main drawback is that SDS remains in the solution with the resulting peptides, which may interfere with the following analyses (e.g., mass spectrometric analysis). Please design a feasible chromatographic method to remove SDS from peptide mixtures (state your choice and briefly explain the rationale).

4) (16 points) Indiana's water has high mineral content and these are mainly the calcium and magnesium minerals. The degree of hardness of the water increases, when more calcium and magnesium dissolve. Hard water is known to clog pipes and to complicate soap and detergent dissolving in water. In a household, a water softening machine is usually used to soften the water. The heart of a water softener is an ion-exchanger. Please briefly describe (if necessary, draw a diagram to illustrate it) the theory how it works and how the water softener can be used year by year.

5) (36 points) For each question, only one item is correct. Write down your choice beside the problem number. 3 points for each question.

(1). Of the following waves, which one has the longest wavelength? (A) Microwave; (B) Radio wave; (C) Infrared light; (D) Gamma rays.

(2). Of the following materials, inside which does a light travels the slowest?

(A) Air; (B) Water; (C) Cover glass; (D) Vacuum.

(3) When two waves combine in such a way as to reinforce each other because two waves of equal amplitude and wavelength arrive at the same point at the same time. This phenomenon is known as (A) Constructive interference; (B) Standing waves; (C) Destructive interference; (D) Resonance; (E) Beating

(4). When a beam interacts with a tissue sample, which of the following generates a wavelength that is different from the incident beam? (A) Rayleigh scattering; (B) Raman scattering; (C) Mie scattering; (D) Absorption.

(5) The energy of a microwave is comparable to which of the following motion?

(A) Spin orientation; (B) Molecular rotation; (C) Chemical bond stretch vibration; (D) Chemical bond bending vibration.

(6) Of the following processes, which one is the slowest? (A) Fluorescence emission; (B) Electronic absorption; (C) Vibration relaxation; (D) Phosphorescence emission.

(7) Of the following modes, which one has the lowest wavenumber?

(A) C-H aliphatic stretch; (B) C-O stretch; (C) C-H aromatic stretch; (D) O-H stretch.

(8) Of the following lasers, which one has the longest wavelength?

(A) Ti:sapphire laser; (B) Dye laser; (C) Argon ion laser; (D) CO_2 laser.

(9) Of the following substances, which one is not an endogenous fluorophore in humans?

(A) Flavins; (B) GFP; (C) NADH; (D) Tryptophan.

(10) An epi-detected fluorescence microscope is installed with a 40 X condenser, a 60X oil immersion objective, and a 10X eyepiece. What is the total magnification?

(A) 2400 X; (B) 400 X; (C) 600 X; (D) 24000 X.

(11) Of the following fluorophores, which one does not need optical excitation to emit luminescence? (A) GFP; (B) NADH; (C) Luciferin; (D) Ethyl Nile Blue.

(12) Which of the following items does not affect the spatial resolution of a microscope? (A) Wavelength; (B) Numerical aperture; (C) Immersion medium; (D) Laser intensity.

CUMULATIVE EXAMINATION IN BIOCHEMISTRY

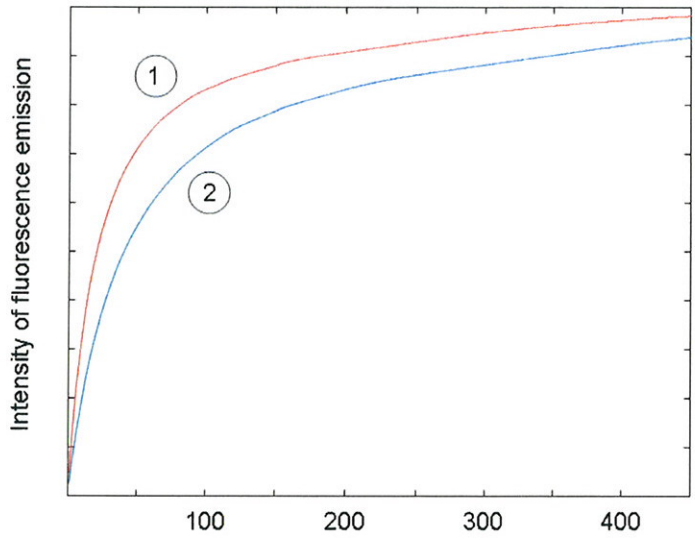
May 1, 2010

Please, provide succinct, straight-to-the-point answers. All questions carry the same weight. Some questions do not require any background knowledge and can be answered based entirely on logical reasoning.

1. Lipid bilayers inside living organisms assume a variety of different shapes (think of cell membranes, various transport vesicles, and tubules). In some case the bilayer surfaces are relatively flat; in other cases they display a very high degree of curvature. One of the nature's ways of forming a membrane with high degree of curvature is to employ a mixture of different phospholipids. For example, a membrane is constructed from phospholipid molecules of two different sorts. Please, explain how the curvature is obtained in this way (supply a sketch if necessary).

2. Human folate receptor β is a medium-sized protein containing 8 disulfide bridges. It is also extremely difficult (impossible) to achieve bacterial expression of this protein. Please, explain the causal connection between these two observations.

3. Crk SH3 domain contains a single tryptophan residue located at the binding interface. The intrinsic fluorescence from this tryptophan can be used to implement a ligand-binding assay. The results from such assay, involving ligands (1) and (2), are plotted below. Which of the two ligands has a better binding affinity (i.e. tighter binding)? Please justify. Assume that both ligands form 1:1 complex with Crk SH3.



4. Two proteins, barnase and barstar, are known for their very fast association rate, k_{on}~10^9 M^{-1} s^{-1}. However, when ionic strength of the solution is increased (i.e. in the presence of high concentration NaCl) the association rate drops dramatically – to k_{on}~10^5 M^{-1} s^{-1}. Please, explain the cause of this behavior.

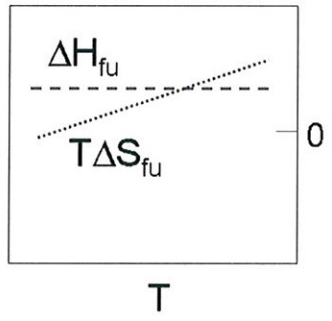
5. "Purines are synthesized de novo in 10 chemical steps that are catalyzed by six enzymes in eukaryotes. ... We applied fluorescence microscopy to HeLa cells and discovered that all six enzymes colocalize to form clusters in the cellular cytoplasm. The association and dissociation of these enzyme clusters can be regulated dynamically, by either changing the purine levels of or adding exogenous agents to the culture media. Collectively, the data provide strong evidence for the formation of a multi-enzyme complex, the "purinosome", to carry out de novo purine biosynthesis in cells." (from An, Kumar, Sheets, and Benkovic: Science 320, 103 (2008))

What is the advantage of assembling all 6 enzymes into the complex (purinosome)? Predict the response of purinosome (in terms of association/dissociation) to (*i*) purine-depleted or, alternatively, (*ii*) purine-rich media culture media.

6. Amyloid plaques are a hallmark feature of a number of neurological diseases. Structural studies of amyloids, however, proved to be extremely difficult. In particular, essentially no high-resolution crystallographic structures have ever been obtained. Why?

7. Anfinsen's dogma suggests that protein primary sequence uniquely determines its 3D fold (one sequence – one fold). Is it possible – at least in theory – to design a sequence which would assume, with roughly equal probability, two different folds? Please, justify with structural and/or thermodynamic arguments.

8. The diagram below is a highly simplified representation of protein thermodynamics, i.e. the balance between the folded (f) and unfolded (u) states. Based on this diagram, please rationalize the effect of protein heat denaturation.



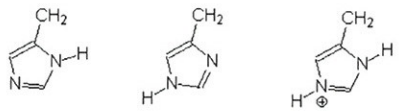
9. Blood is buffered and maintained in a relatively narrow range of pH around 7.4. The following equilibrium is primarily responsible for the buffering effect:

$$H^+ + HCO_3^- \rightleftarrows H_2CO_3 \rightleftarrows H_2O + CO_2(g)$$

When a person hyperventilates – for example, in the case of a panic attack – the level of CO_2 in his/her blood drops. To restore the level of CO_2 it is sometimes recommended to breath into a brown bag.

What happens with blood pH when a person breaths in and out of a paper bag (i.e. when the concentration of CO_2 in his/her blood goes up)? Please, justify your answer.

10. Normally, histidine side chain has a pK_a of ca. 6 (at lower pH histidine side chain is doubly protonated; at higher pH it is singly protonated). However, under certain circumstances this pK_a value can be increased. For instance, in the catalytic triad of serine proteases, histidine side chain forms a hydrogen bond with adjacent aspartate side chain. This interaction increases histidine's pKa and basicity. Please, explain the nature of this effect.



Inorganic Chemistry Cumulative Exam

Purdue University

May 1, 2010

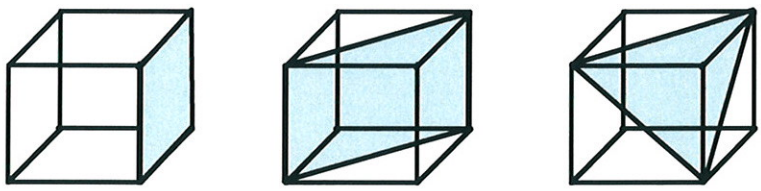
There are 100 possible points in this exam.

1. (20 points) For each substance or structure given in (a)-(j), select the appropriate composition.

(a) Perovskite
(b) Ruby
(c) Quartz
(d) Rutile
(e) Pyrite
(f) Apatite
(g) Brass
(h) White Gold
(i) Mica
(j) Cinnabar

(1) SiO_2	(2) $BaTiO_3$	(3) AuNi
(4) Ca_3SiO5	(5) CuSn	(6) Al_2O_3
(7) FeS_2	(8) TiO_2	(9) $Ca_5(OH)(PO_4)_3$
(10) Pd	(11) HgS	(12) Pt
(13) CuZn	(14) $KAl_2(OH)_2Si_3AlO_{10}$	(15) Al_2O_3 dope with Cr^{3+}
(16) $CuFeO_2$	(17) AuCu	(18) Fe_2O_3
(19) ZnO	(20) PbSe	(21) $BaWO_4$

2 (15 points) The unit cell of Au has a face-centered cubic symmetry. Calculate how many Au atoms are present in (100), (110) and (111) planes per area of a^2 when a is the unit cell parameter of Au. Figures below show (100), (110) and (111) planes (i.e. Miller indices) of a cubic unit cell.

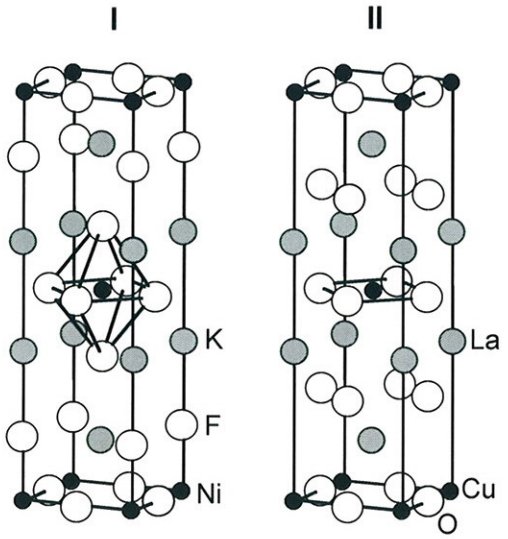


(100) (110) (111)

3. Answer the following questions regarding the NaCl structure.

(a) (5 points) Draw a unit cell crystal structure. Use a filled circle to represent Na and an empty circle to represent Cl.
(b) (5 points) What is the local geometry and coordination number of Na in this structure?
(c) (10 points) Draw an atomic arrangement in the (111) and (110) plane. Indicate the shortest atomic distance (Na-Na, Na-Cl, or Cl-Cl) in each plane in terms of the unit cell length a.

4. Unit cells of two compounds **I** and **II** are shown below.



(a) (10 points) Write the empirical formula of **I** and **II**.
(b) (5 points) What is the coordination number of La in **II**?
(c) (5 points) Compound **I** has a tetragonal structure with a = b = 3.88 Å and c = 12.60 Å. Calculate the density of **I**.
(d) (5 points) The local coordination of Cu ion in **II** is square planar. Is it a common local structure for Cu ion? Explain in terms of the electronic configuration of Cu ions in compound **II**.

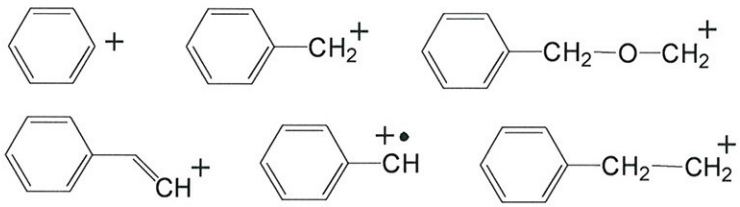
5. (20 points) Give an example of solid state catalysts. Include answers for the following questions in your example.

What is the composition of the catalyst?
Which reaction does it catalyze?
What is the mechanism? Or how does it catalyze the reaction?

An article was published in *J. Am. Chem. Soc.* in the March 30, 2010 issue that is titled "Formation of Beyerene, Kaurene, Trachylobane, and Atiserene Diterpenes by Rearrangements That Avoid Secondary Carbocations" (by Hong and Tantillo). This paper shows computational results in support of formation of the named diterpenes via very complex rearrangements involving tertiary carbocation intermediates, thus avoiding the formation of secondary carbocations. Please answer the following questions to demonstrate your understanding on carbocations and the mechanisms of their rearrangements.

1) Why would this system try to avoid the formation of secondary carbocations?

2) Resonance stabilized carbocations are often more stable than other types of carbocations (with the exception of tertiary ones). Which of the following carbocations are resonance stabilized and which are not? Justify your answers by drawing the most important resonance structures and the relevant orbitals. Which one(s) is(are) kinetically unstable? Again, justify. Also, please tell what "kinetically stable" and "thermodynamically stable" mean.



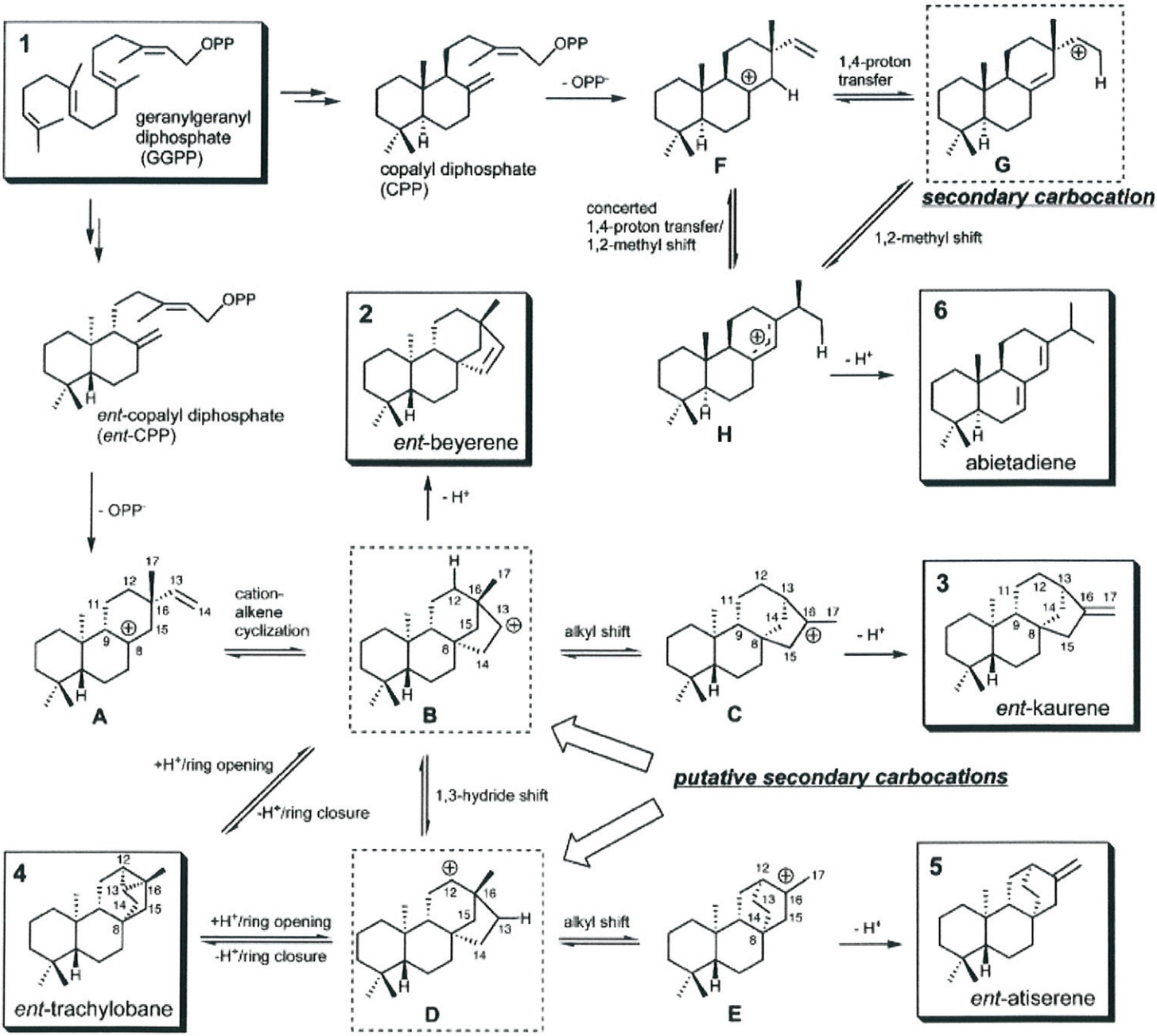
3) The scheme on next page (**Scheme 1**; published before this paper) shows a proposal for enzyme-catalyzed formation of the diterpenes. Show the mechanisms for transitions **F** to **G**, **F** to **H**, **B** to **D**, and **D** to **E** (indicate forming and breaking of bonds with arrows for the transition states).

4) This article presents alternative pathways that avoid formation of secondary carbocations by combining two or more mechanistic steps into concerted processes that form tertiary carbocations. Some of these pathways are shown in **Scheme 2**. Please provide mechanisms for transitions **A1** to **C1** and **C2** to **E** (indicate forming and breaking of bonds with arrows for the transition states). What can you say about the nature of the key transition states compared to those transition states that lead to formation of secondary carbocations in Scheme 1?

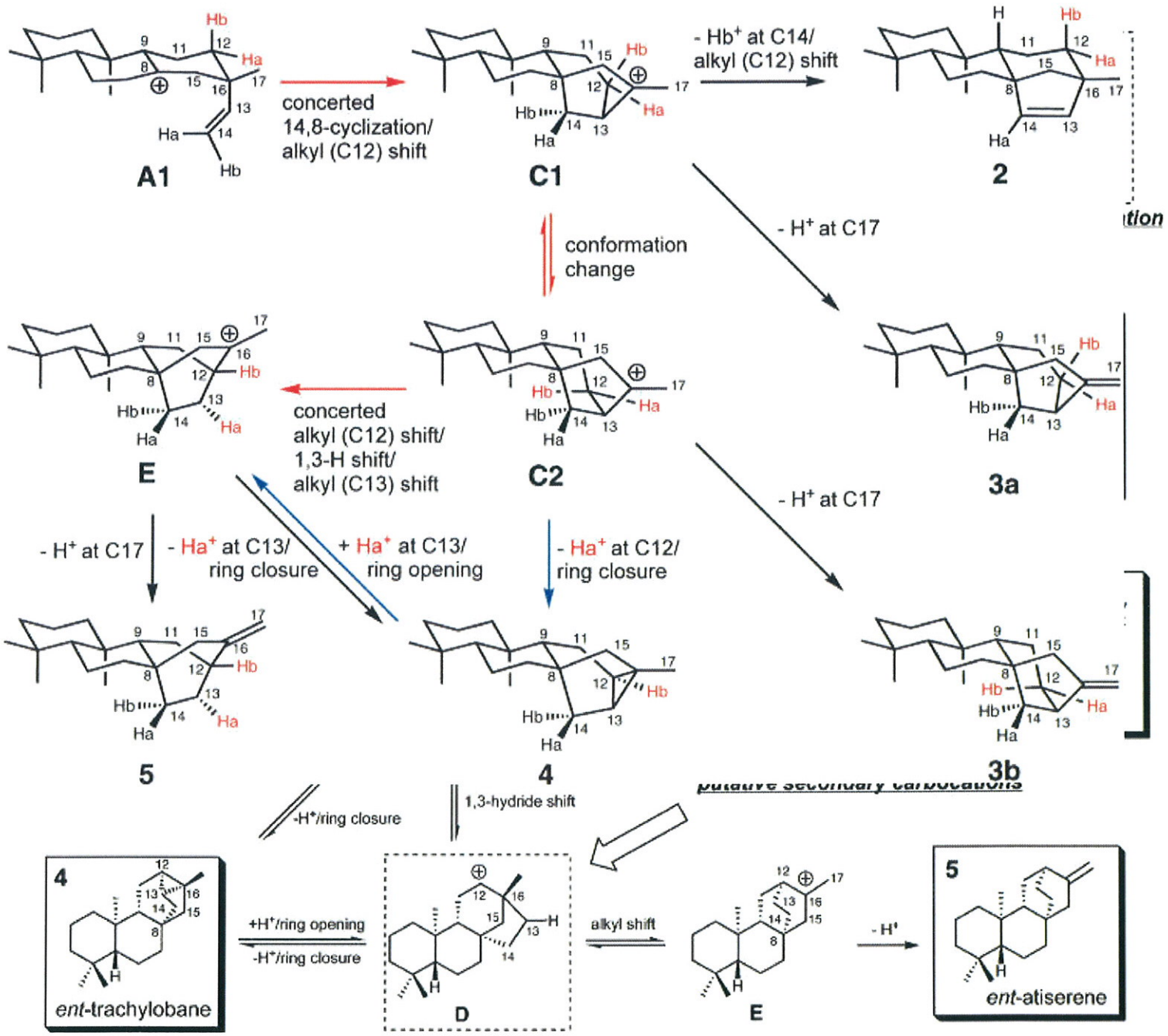
5) What are the implications of this study on the formation of the diterpenes of interest?

6) What are the broader implications of this study about secondary carbocations?

Scheme 1.


1
OPP
geranylgeranyl diphosphate (GGPP)
OPP
copalyl diphosphate (CPP)
- OPP⁻
F
1,4-proton transfer
G
secondary carbocation
concerted 1,4-proton transfer/ 1,2-methyl shift
1,2-methyl shift
OPP
ent-copalyl diphosphate (ent-CPP)
2
ent-beyerene
H
- H⁺
6
abietadiene
- OPP⁻
- H⁺
cation-alkene cyclization
A
B
alkyl shift
C
- H⁺
3
ent-kaurene
+H⁺/ring opening
-H⁺/ring closure
1,3-hydride shift
putative secondary carbocations
4
ent-trachylobane
+H⁺/ring opening
-H⁺/ring closure
D
alkyl shift
E
- H⁺
5
ent-atiserene

Scheme 2.


A1
concerted
14,8-cyclization/
alkyl (C12) shift
C1
- Hb+ at C14/
alkyl (C12) shift
2
conformation
change
- H+ at C17
E
concerted
alkyl (C12) shift/
1,3-H shift/
alkyl (C13) shift
C2
3a
- H+ at C17
- H+ at C17
- Ha+ at C13/
ring closure
+ Ha+ at C13/
ring opening
- Ha+ at C12/
ring closure
5
4
3b
-H+/ring closure
1,3-hydride shift
4
ent-trachylobane
+H+/ring opening
-H+/ring closure
D
alkyl shift
E
- H'
5
ent-atiserene

Physical Cumulative Examination
May 1, 2010

(1) The movement of gas particles is described by kinetic gas theory, which provides predictions about important gas particle properties, such as their velocity distribution and collision frequency.

(a) The velocity distribution of gas particles is given by the Maxwell distribution of particle speeds. Illustrate schematically the temperature-dependence and molecular-weight dependence of the Maxwell velocity distribution.

(b) Cs atoms (molecular weight: $132.9 gmol^{-1}$) are added to a previously evacuated container of a volume V=1 liter (size). At what pressure, P, does the mean free path, $l=\langle u\rangle/z$ ($\langle u\rangle$: mean velocity; z: total number of collisions of a single atom per second), of Cs at 25°C become comparable to the size of the container? Assume ideal gas conditions. The collision cross-section is $\sigma=9.16*10^{-19}m^2$ and the Boltzmann constant is $k=1.38*10^{-23}JK^{-1}$. The number of collisions per atom is given with (N: number of Cs atoms):

$$z = \frac{\sqrt{2}\sigma\langle u\rangle N}{V}$$

(2) The diffusion properties of particles in solution are described by Fick's first and second laws of diffusion

$$J_x = -D\left(\frac{dN(x)}{dx}\right) \qquad (1)$$

$$\frac{dN(x,t)}{dt} = D\frac{d^2N(x,t)}{dx^2} \qquad (2)$$

and by the Stokes Einstein relationship

$$D = \frac{kT}{f} = \frac{kT}{6\pi\eta r}. \qquad (3)$$

(a) Derive Fick's second law of diffusion from Ficks first law of diffusion.

(b) Confocal fluorescence correlation spectroscopy is a modern confocal spectroscopy (FCS) technique that allows for the characterization of diffusion properties. This technique detects fluorescence fluctuations caused by fluorescently labeled molecules during their movement through the confocal spot (confocal spot size corresponds to size of *Ecoli* bacterium). The fluorescence fluctuations can be analyzed in terms of an autocorrelation analysis, thus providing information about the diffusion times of these fluorescent probes during passage through the confocal volume. Explain why Eq. 3 can provide the theoretical basis for such FCS studies!

(c) The diffusion coefficient D of ribonuclease from bovine pancreas, an enzyme that digests RNA, has been measured in a dilute buffer at 20°C (viscosity: $1.0*10^{-2}gs^{-1}cm^{-1}$). The diffusion value is $D=131\mu m^2s^{-1}$. Assuming that the molecule is a sphere, calculate the radius of ribonuclease in units of nm.

(3) In a sedimentation experiment, the following forces act on a particle:

Frictional force: $F_{fr} = -fv_x$

Gravitational force: $F_{gr} = mg$

The buoyant force: $F_b = -mV\rho g$

(a) Show that the sedimentation coefficient s is expressed by

$$s = \frac{v_{x,ter}}{g} = \frac{m(1 - V\rho)}{f}$$

where $v_{x,ter}$ is the terminal velocity.

(b) The following data have been obtained for ribosomes from a paramecium at 20°C: $s=82.6*10^{-13}s$, $D=1.52*10^{-7}cm^{-2}s^{-1}$, $V=0.61cm^3g^{-1}$, $R=8.314JK^{-1}mol^{-1}$. Assume the density of water. Calculate the molecular weight of the ribosomes.

Periodic Classification of the Elements

I A	II A	III B	IV B	V B	VI B	VII B	VIII			I B	II B	III A	IV A	V A	VI A	VII A	O
1 H 1.00797																	2 He 4.0026
3 Li 6.939	4 Be 9.0122											5 B 10.811	6 C 12.01115	7 N 14.0067	8 O 15.9994	9 F 18.9984	10 Ne 20.183
11 Na 22.9898	12 Mg 24.312											13 Al 26.9815	14 Si 28.086	15 P 30.9738	16 S 32.064	17 Cl 35.453	18 Ar 39.948
19 K 39.102	20 Ca 40.08	21 Sc 44.956	22 Ti 47.90	23 V 50.942	24 Cr 51.996	25 Mn 54.9380	26 Fe 55.847	27 Co 58.9332	28 Ni 58.71	29 Cu 63.54	30 Zn 65.37	31 Ga 69.72	32 Ge 72.59	33 As 74.9216	34 Se 78.96	35 Br 79.909	36 Kr 83.80
37 Rb 85.47	38 Sr 87.62	39 Y 88.905	40 Zr 91.22	41 Nb 92.906	42 Mo 95.94	43 Tc (99)	44 Ru 101.07	45 Rh 102.903	46 Pd 106.4	47 Ag 107.870	48 Cd 112.40	49 In 114.82	50 Sn 118.69	51 Sb 121.75	52 Te 127.60	53 I 126.9044	54 Xe 131.30
55 Cs 132.905	56 Ba 137.34	57 La* 138.91	72 Hf 178.49	73 Ta 180.948	74 W 183.85	75 Re 186.2	76 Os 190.2	77 Ir 192.2	78 Pt 195.09	79 Au 196.967	80 Hg 200.59	81 Tl 204.37	82 Pb 207.19	83 Bi 208.980	84 Po (210)	85 At (210)	86 Rn (222)
87 Fr (223)	88 Ra (226)	89 Ac† (227)															

*Lanthanides	58 Ce 140.12	59 Pr 140.907	60 Nd 144.24	61 Pm (147)	62 Sm 150.35	63 Eu 151.96	64 Gd 157.25	65 Tb 158.924	66 Dy 162.50	67 Ho 164.930	68 Er 167.26	69 Tm 168.934	70 Yb 173.04	71 Lu 174.97
†Actinides	90 Th 232.038	91 Pa (231)	92 U 238.03	93 Np (237)	94 Pu (242)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (249)	99 Es (254)	100 Fm (253)	101 Md (256)	102 No (256)	103 Lw (257)

(Numbers in parentheses are the mass numbers of the most stable isotopes.)