Department of Chemistry
Cumulative Examinations

April 22, 2017

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.

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 Cume Exam – April 2017
Topic: Analytical data evaluation; IR, Florescence, and Absorption spectroscopy

A) (10 points) Define or give a mathematical equation for the following terms:
1. Accuracy
2. Precision
3. Determinate error
4. Absolute uncertainty
5. Mode (of a distribution)
6. Gaussian distribution
7. Method of Least squares
8. Degrees of Freedom
9. Primary Standard
10. Back titration

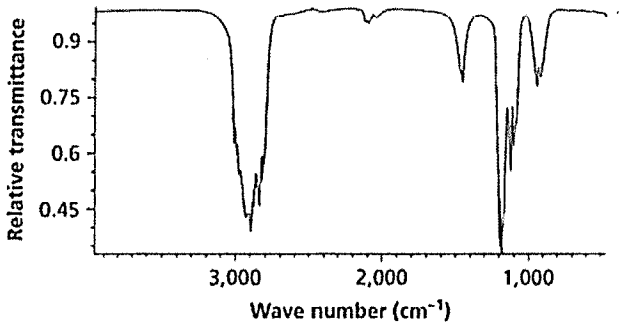
B) (10 points) While doing a measurement you get the following 4 numbers for the concentration of iron in a sample: 0.1015, 0.0991, 0.1016, and 0.1017. What is the mean, the 95% confidence interval for normally distributed noise, and the relative standard deviation for this data set? (see equations and table at the end of the exam).

C) (5 points) You calculate a relative standard deviation in the previous question. I usually regard the relative standard deviation as a measure of the relative error on your mean. You also calculated a confidence interval, which is also a measure of the uncertainty of the mean. Compare and contrast these numbers. Which is the better measure of experimental uncertainty?

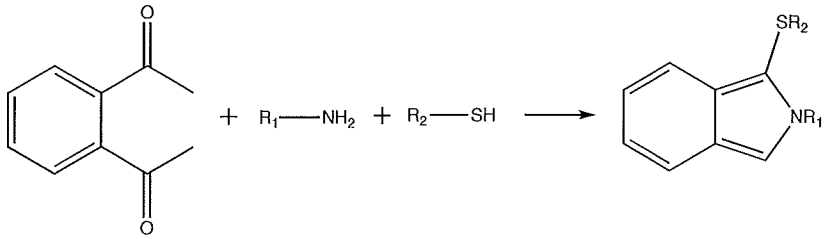
D) (15 points) Carbon has two common isotopes, ^{12}C and ^{13}C, with relative isotopic abundances of, respectively, 98.89% and 1.11%. (a) What are the mean and standard deviation for the number of ^{13}C atoms in a molecule of cholesterol given binomial probability distribution? (b) What is the probability of finding a molecule of cholesterol ($C_{27}H_{44}O$) containing no atoms of ^{13}C? (c) What is the probability of finding a molecule of cholesterol ($C_{27}H_{44}O$) containing one atom of ^{13}C?
(see equations at the end of the exam).

E) (10 points) Describe three methods for performing an IR measurement on different sample types (e.g. liquids vs powders)?

F) (10 points) The IR spectrum shown below belongs to a compound with formula C_2H_6O. Assign the peaks at ~2900 cm^{-1} and ~1200 cm^{-1}, and determine the identity of the compound.



G) (10 points) Primary amino acids can be detected by fluorescence spectroscopy after derivatization with a molecular tag that is a strong fluorophore. Would the following derivative reaction produce a flourophoric amino acid? Why or why not?



H) (10 points) Assuming the above derivative is flourophoric, design a laser-induced fluorescence detection system for it that might be coupled to HPLC. Draw the schematic.

I) (10 points) Write an equation for the laser-induced fluorescence intensity and indicate the variables. Indicate two ways the quantum efficiency (Φ) of a fluorophore be increased in an experiment?

J) (10 points) The drug tolbutamine (MW = 270.0 g mol^{-1}), a treatment for type 2 diabetes, has a molar absorptivity of 703 $M^{-1}cm^{-1}$ at 262 nm. One tablet was dissolved in 250.00 mL of water. A 10.00 mL aliquot of this solution was diluted to 100.00 mL in a volumetric flask. This diluted solution exhibited an absorbance of 0.275 at 262 nm in a 1.00-cm cell. Calculate the mass (**in mg**) of tolbutamine in the tablet.

Equations

$c = \lambda\nu$

$E = h\nu = hc/\lambda$

$A=\varepsilon bc$

Normal distribution:

$$s^2 = \frac{\sum_{i=1}^{n}(X_i - \overline{X})^2}{n-1} \qquad \mu = \overline{X} \pm \frac{ts}{\sqrt{n}}$$

Binomial distribution:

$$P(X,N)=\frac{N!}{X!(N-X)!} \times p^X \times (1-p)^{N-X}$$

where $P(X,N)$ is the probability that a given outcome will occur X times during N trials, and p is the probability that the outcome will occur in a single trial.

Mean : $\mu = Np$

Variance : $\sigma^2 = Np(1-p)$

Values of *t* for the 95% Confidence Interval

Degrees of Freedom	*t*
1	12.71
2	4.30
3	3.18
4	2.78
5	2.57
6	2.45
7	2.36
8	2.31
9	2.26
10	2.23
12	2.18
14	2.14
16	2.12
18	2.10
20	2.09
30	2.04
50	2.01
∞	1.96

Biochemistry Cumulative Exam

Title: Nucleic Acids

April 22, 2017

1. **(10 points)** Why using bromo-deoxyUTP instead of TTP can lead to mutations in DNA?
2. **(10 points)** Provide all the steps of rRNA processing in prokaryotes.
3. **(20 points)** Provide any four differences between a miRNA and a siRNA.
4. **(10 points)** Define the following terms in 2-3 sentences: (a) Riboregulators (b) Riboswitches.
5. **(10 points)** Provide any one mechanism by which a double stranded DNA break is repaired in cells.
6. **(20 points)** (a) How fast does template DNA spin (expressed in revolutions per second) at an E coli replication fork?

   (b) What is the velocity of movement (in micrometers per second) of DNA polymerase III holoenzyme relative to the template?
7. **(10 points)** Telomerase is not active in most human cells. Some cancer biologists have suggested that activation of the telomerase gene would be a requirement for the cells to become cancerous. Explain why this might be the case?
8. **(10 points)** Provide all the steps for generating a cDNA library from human liver cells.

Inorganic Cume
April 22, 2017

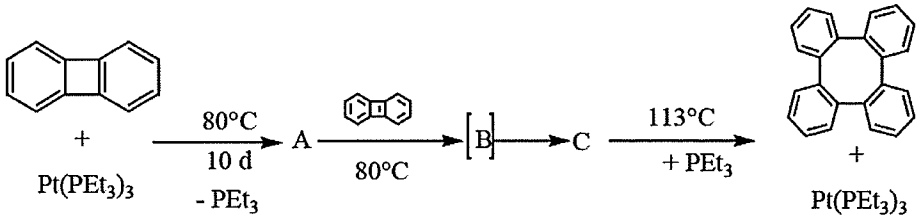
Organometallic Chemistry

Please answer the following questions as completely as possible. Partial credit will be given in instances where work and thought process is shown.

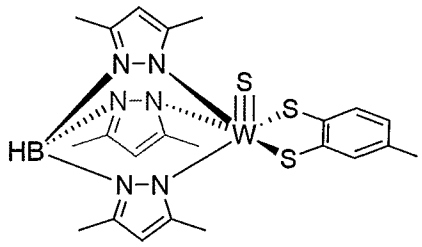
1. (15 points-5 points each) The dimeric compound $[(\eta\text{-}C_5Me_5)Cr(CO)_2]_2$ (**A**) obeys the 18 electron rule and shows IR absorptions around 1870 cm^{-1}. **A** on treatment with excess CO at 1200-1450 psi and 175 °C for 10 hrs gave another dimeric chromium compound **B** which also obeys the 18 electron rule and also showed absorptions around 1876 cm^{-1}. Photolysis of **A** with UV radiation was found to result in a 17 electron dimeric compound **C** along with the release of CO gas. IR spectrum of **C** showed a single band at 1788 cm^{-1} and analysis showed it to have the same bond order as compound **A** between the chromium atoms. Draw the structures of **A**, **B** and **C** clearly indicating Cr-Cr bond order and nature of CO bonding.

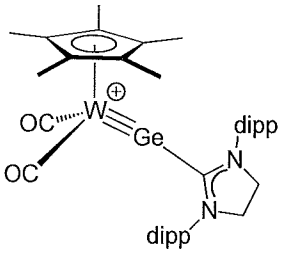
2. (40 points-8 points each) Reaction of OsO_4 with CO at 125 °C and 75 atm was found to result in a stable compound **A** with the empirical formula OsC_4O_4. Compound **A** was found to contain 3 metal-metal bonds. Reaction of **A** with excess of sodium metal followed by treatment with H_3PO_4 was found to result in compound **B** with the molecular formula $OsH_2C_4O_4$. Heating of **B** was found to result in the release of a colourless gas and formation of a compound **C** with empirical formula $OsHC_4O_4$. **C** on treatment with MeI was found to get converted to **D** with release of a hydrocarbon gas. **D** on further treatment with Na/Hg followed by MeI gave **E** with the empirical formula $OsC_5H_3O_4$. Compounds **A-E** obey 18 electron rule and all of them show infrared absorptions in the vicinity of 2000 cm^{-1}. No bridging ligands were also observed. Suggest structures for compounds **A-E**.

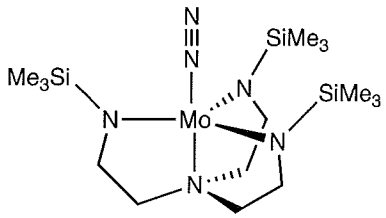
3. (15 points-5 points each) The reaction of $Pt(PEt_3)_3$ with 1 mole of biphenylene over a period of 10 days at 80 °C was found to result in a 16 electron compound **A** along with the release of PEt_3. Compound **A** on further reaction at 80 °C with one more mole of biphenylene was found to give a 16 electron compound **C** through an 18 electron intermediate **B**. Reaction of **C** with PEt_3 at 113 °C was found to give tetraphenylene along with $Pt(PEt_3)_3$. Write the structures of **A**, **B** and **C**. Indicate type of reactions happening at all stages.

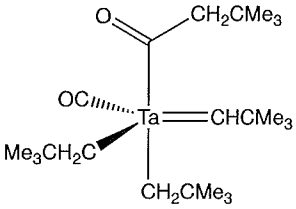


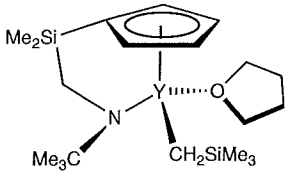
4. (30 points-5 points each) Provide the oxidation state, d electron count, and valence electron count for the following molecules:

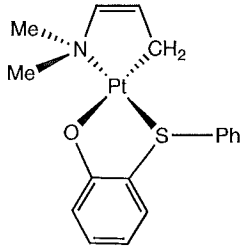








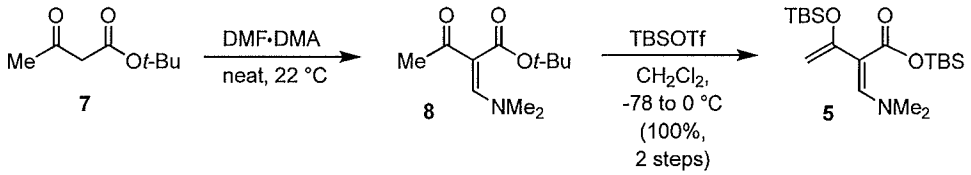




Organic Division Exam

April 2017

1. Shenvi and Reiher (*J. Am. Chem. Soc.* **2017**, *139*, 3647-3650), during their synthesis of Kalihinol C, have carried out the following reactions as shown in the attached article.

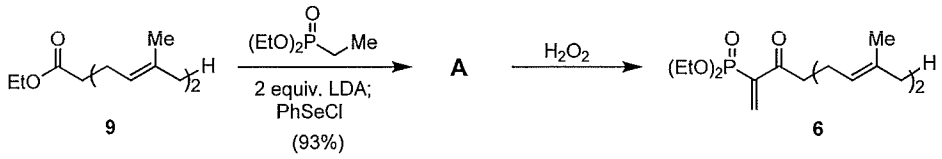


a. Write down the full name and chemical structures of DMF • DMA.

b. Show the stepwise mechanism of formation of compound **8**.

c. Write the stepwise mechanism for the formation of TBS ester **5**.

2. Ester **9** was converted to diethylphosphonate derivative **6** in a two-step sequence.

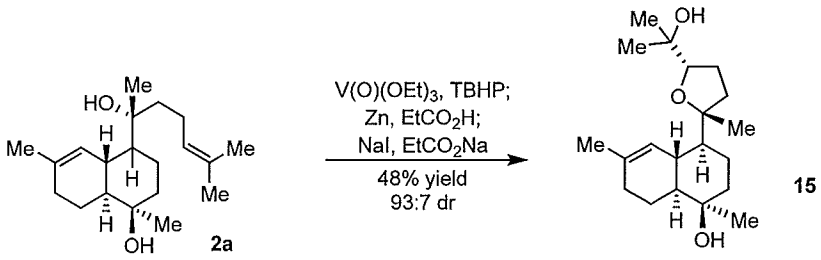


a. Draw the product intermediate **A** for the first step reaction with LDA and $(EtO)_2P(O)$-CH_2CH_3, followed by the addition of PhSeCl.

b. Show the mechanism for the second step reaction with H_2O_2.

3. Write the full name and draw the chemical structures for DMDO, TFAA, TMSCN, TBSOTf, and HFIP.

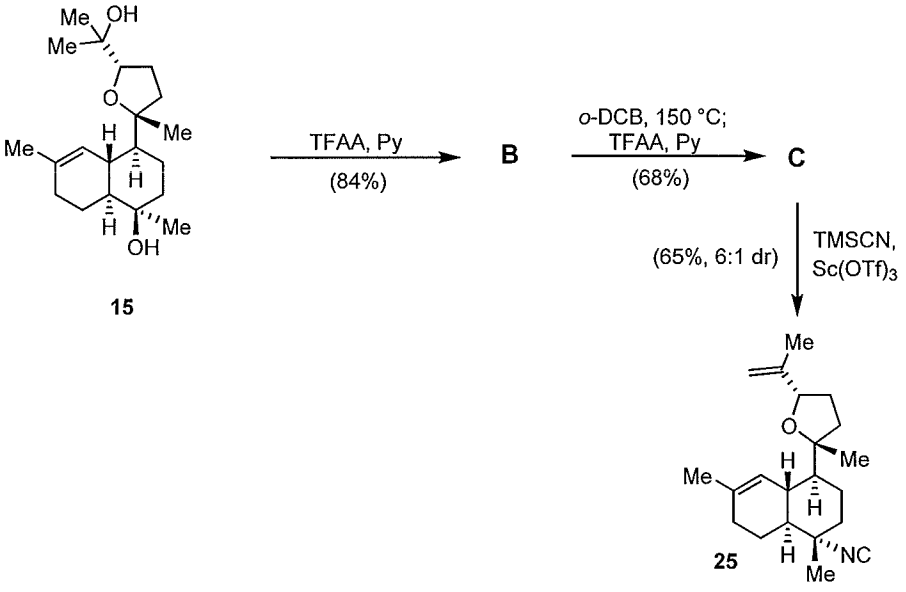
4. Treatment of **2a** (protokalihinol) with $V(O)(OEt)_3$, TBHP followed by a reaction with Zn, $EtCO_2H$ and NaI, $EtCO_2Na$ provided tetrahydrofuran derivative **15** and its diastereomer in 48% yield and diastereomeric ratio (dr) of 93:7.



a. Show stepwise formation of the tetrahydrofuran intermediate formed with $V(O)(OEt)_3$, TBHP (before deoxygenation with Zn, $EtCO_2H$ and NaI, $EtCO_2Na$).

b. Draw the structure of the minor (7%) diastereomer formed after these reactions.

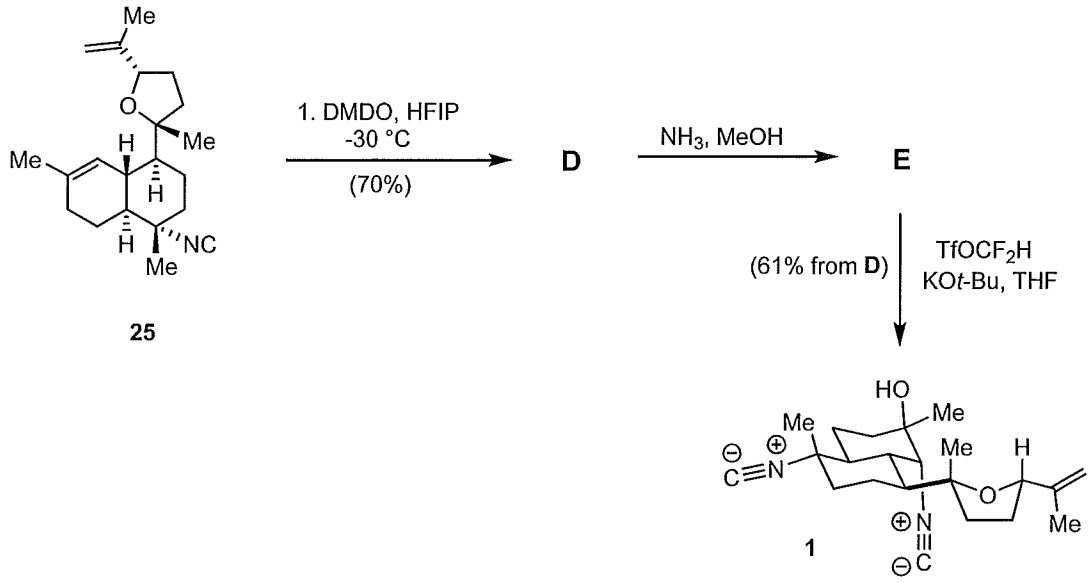
5. Tetrahydrofuran derivative **15** was converted to nitrile derivative **25** in three-step sequence through the intermediates **B** and **C**.



a. Draw the product structures for **B** and **C** with proper stereochemistry.

b. Propose a mechanism for the reaction of **C** with TMSCN and $Sc(OTf)_3$ leading to the formation of nitrile **25**.

6. Tetrahydrofuran derivative **25** was converted to Kalihinol (**1**) in a three-step sequence through intermediates **D** and **E**.



a. Identify intermediates **D** and **E** with appropriate stereochemistry.

b. Rationalize why products **D** and **E** are formed stereoselectively.

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Communication

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Stereocontrolled Synthesis of Kalihinol C

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Supporting Information

ABSTRACT: We report a concise chemical synthesis of kalihinol C via a possible biosynthetic intermediate, "protokalihinol", which was targeted as a scaffold en route to antiplasmodial analogs. High stereocontrol of the kalihinol framework relies on a heterodendralene cascade to establish the target stereotetrad. Common problems of regio- and chemoselectivity encountered in the kalihinol class are explained and solved.

The kalihinols (Figure 1) possess the highest skeletal and functional group complexity of the biologically enigmatic isocyanoterpene (ICT) class.[1,2] Kalihinol A[3a] also exhibits the highest reported potency of the ICTs against *Plasmodium falciparum*,[3b] killing with an EC_{50} of 1 nM, but the mechanism of action has not been rigorously assigned. Proposed mechanisms to explain phenotypic effects of the ICTs include inhibition of heme detoxification[4] or copper chelation,[5] but these proposals do not fully account for the structure–activity relationships and life-cycle activities reported. For example, our discovery that the amphilectenes and adocianes are cytotoxic against liver-stage parasites militates against heme detoxification inhibition as the exclusive antiplasmodial mechanism.[6] Copper chelation is simply not possible for congeners with distant isonitriles. As part of a program to investigate the biological activity of ICTs, we have begun to develop effective chemical syntheses[2,6,7] and associated methods[8] to produce and modify three main structural classes: amphilectenes, adocianes, and kalihinols.[1,2] Prior syntheses[9] of the kalihinol class have fought to control stereochemistry in the functionally dense scaffolds, and each contains at least one uncontrolled (ca. 1:1 d.r.) stereogenic step.[10] Here we report a short and fully stereocontrolled synthesis of kalihinol C (**1**) enabled by a new heterodendralene building block, a directed alkene isomerization, and a new method for isonitrile synthesis.

The kalihinols appear to derive from a common intermediate, a "protokalihinol" (**2a**) where the tetrahydrofurans or -pyrans derive from oxidative cyclization of a pendant prenyl unit. The protokalihinol framework (a dihydroxy-bifloran diterpene)[1] would arise from bisabolyl cation intermediate **3** via cation-olefin cyclization and concomitant stereoselective capture of water.[11] Although such a pathway might globally simplify formation of the kalihinol stereotetrad (in blue), we thought intramolecular capture of oxygen in synthon **4** might be more realistic than stereoselective carbocation hydration.[12]

Recently, our lab reported short syntheses of amphilectene[7] and adociane[6] ICTs that relied on a new class of polarized dendrimeric polyene[13] (Danishefsky dendralenes) that forged the stereochemically dense core of these and other terpenes[14] in highly diastereoselective Diels–Alder cascades. Given the structural correspondence between amphilectenes and kalihinols, we realized that a dendralene-based approach might emulate the proposed biosynthetic pathway if the oxynucleophile of **4** were embedded in a dendralene.

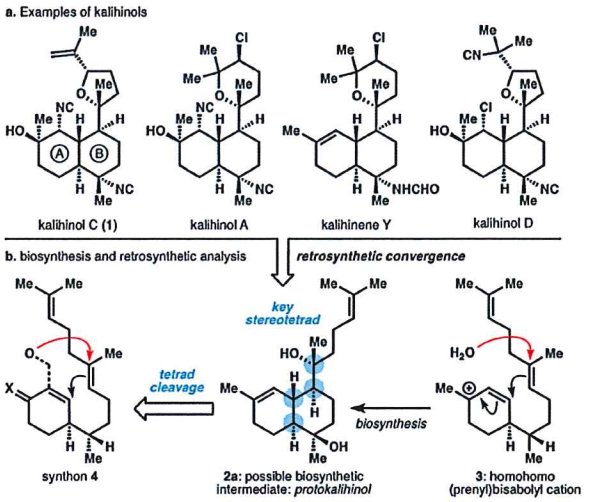
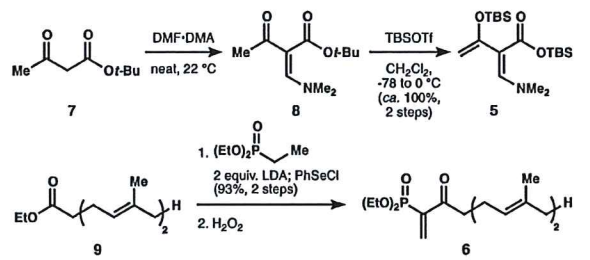


Figure 1. (a) Kalihinol congeners; (b) hypothetical biosynthesis that informs a proposed chemical synthesis.

Short and efficient routes to the heterodendralene and double-dienophile partners are shown in Scheme 1. Preliminary reconnaissance identified two important features of each component. First, the dimethylamine substituent[15] in **5** was necessary to offset the electron-withdrawing carboxylate, which rendered the dendralene less reactive with electron-deficient dienophiles. Second, the diethylphosphonate substituent in **6**

Scheme 1. Routes to Building Blocks



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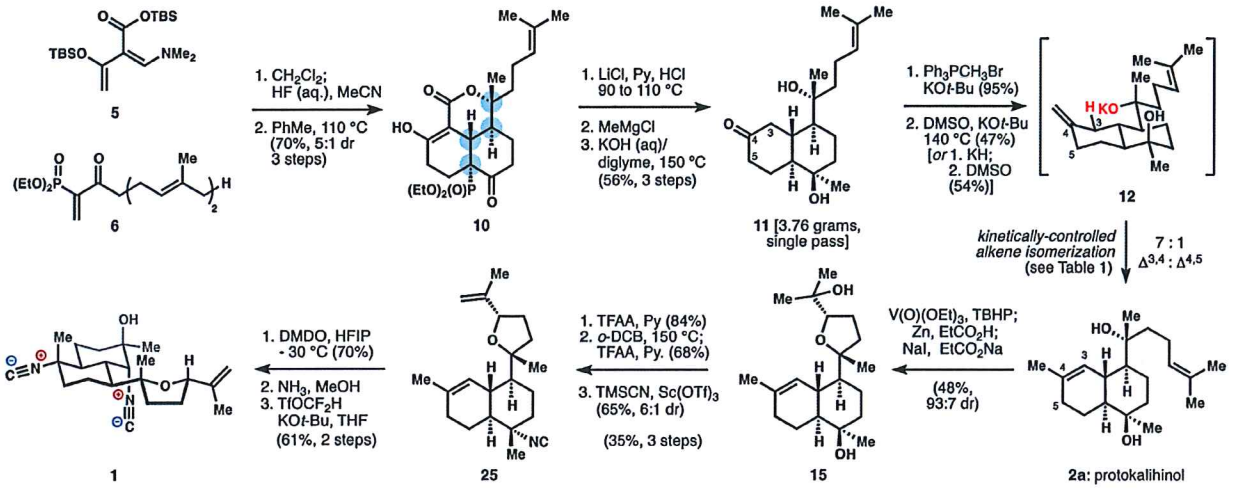
Scheme 2. Synthesis of Kalihinol C



activated the dienophile for ambient-temperature cycloaddition but was not so destabilizing as to complicate isolation.

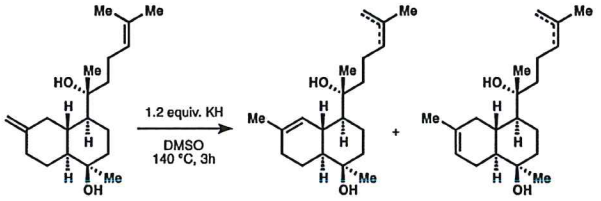
Building block **5** was synthesized by condensation of *tert*-butyl acetoacetate **7** with dimethylformamide dimethyl acetal (DMF-DMA) to yield vinylogous amide **8**, which was doubly silylated to **5** with loss of the *tert*-butyl group. Geranyl-phosphonate **6** was also synthesized in two steps by addition of diethyl ethylphosphonate to ethyl geranylacetate (**9**), followed by in situ selenation and subsequent oxidation/elimination of the selenoxide.[16]

Cycloaddition of **5** to **6** occurred at 22 °C in CH_2Cl_2 to yield an inconsequential mixture of diastereomers at the dimethylamino group, which was eliminated to an enone (see synthon **4**) by treatment with hydrogen fluoride. The silylester was also cleaved to the corresponding unsaturated carboxylic acid, which engaged in a nearly quantitative intramolecular Diels–Alder cycloaddition[17] to provide, after tautomerization, *β*-keto-lactone **10**, possessing the targeted stereotetrad of the kalihinols. The stereoisomers (5:1 ratio) corresponded to epimers at the C–P bond, and were converged in the next step.[18]

Lactone **10** was converted to diol **11** by (1) Krapcho-like dephosphonylation, (2) stereoselective methyl addition to the B-ring ketone, and (3) lactone hydrolysis/decarboxylation; each step deserves some comment. First, the desphonylation is a little-precedented transformation that required the development of a new procedure [LiCl, Py·HCl (aq.), 90→110 °C] to spare the acid-sensitive *tert*-alkyl lactone and the electrophilic ketones, which underwent retro-Dieckmann reactions under other conditions. Addition of a methyl group prior to decarboxylation preserved the *trans*-decalin geometry, whereas the corresponding ketone weakly favored the *cis*-decalin after lactone cleavage. Preferential formation of the disfavored *trans*-decalin (of **11**) has remained unsolved in prior work,[2,9,10] and in this case is enabled by the fused lactone, which locks the geometry. Through this short process, multigram quantities of decalone **11** could be generated in a single pass for elaboration to protokalihinol **2a** and the metabolite itself (**1**).

However, establishment of the required $\Delta^{3,4}$ unsaturation was undermined by formation of the $\Delta^{4,5}$ isomer, which predominated upon enolization of ketone **11**. Such preference is well-precedented for 2-decalone enolizations[19] as well as alkene isomerizations in the heavily studied amorphane sesquiterpenes.[20] Attempts to generate endocyclic alkene **2** by ionization of the tertiary alcohol derived from ketone **11** delivered the isomeric $\Delta^{4,5}$ alkene with unrelenting regularity. Because Brønsted bases can mediate alkene isomerization at high temperatures,[21] we wondered if the tertiary alcohol proximal to the C3 methylene of **11** could mediate a selective alkene isomerization as its strongly basic alkoxide. Indeed, we found that the potassium salt **12** could be heated to 140 °C in DMSO to deliver protokalihinol **2a** with 7:1 selectivity for $\Delta^{3,4}$ unsaturation (**2**) over $\Delta^{4,5}$ (**14**, Table 1). Consistent with this

Table 1. Alkoxide-Directed Alkene Isomerization



entry	variations (and % conversion)	2:14	%2a
1	none (78)	7:1	54
2[a]	4 equiv. KO*t*-Bu, no KH (82)	5:1	55
3[a]	16 equiv. KO*t*-Bu, no KH (86)	1:1	28
4	1.2 equiv. *n*-BuLi, no KH (0)		0
5	DMPU instead of DMSO (0)		0
	alternate conditions		
6[b]	20 mol % $RhCl_3$, EtOH/H_2O, 70 °C (56)	1:1	28
7[a]	2 mol % [Co],[c] 4 mol % $PhSiH_3$, PhH (42)	<1:20	<5

[a]^{1}H NMR. [b]GC–MS. [c]Co(Sal$^{t\text{-Bu},t\text{-Bu}}$)Cl·$H_2O$.

mechanistic model, increased equivalents of base led to increased amounts of **14** (entries 1–3), which would derive from intermolecular deprotonation. Small amounts (ca. 15%) of isomers derived from chain isomerization ($\Delta^{15,16}$: **2b**, **14b**) also were observed, but could be removed from **2a** (or carried forward and removed from **15**). Other alkali metals besides potassium and other solvents besides DMSO performed poorly (entries 4 and 5; see SI for a list of other variations). Methods like coordinative isomerization[22] or HAT isomerization[23]

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(entries 6 and 7) delivered mixtures of alkenes or the $\Delta^{4,5}$ isomer exclusively.

A Sharpless-type directed epoxidation[24] was identified as the only method capable of controlling the stereochemistry of the targeted tetrahydrofuran. But to our chagrin, the $\Delta^{3,4}$ ring-alkene reacted faster than the $\Delta^{14,15}$ chain-alkene and delivered a C3,4 epoxide opposite to that required for elaboration to the isocyano-hydrin of **1** (**16**, see Figure 2). Fortunately, these

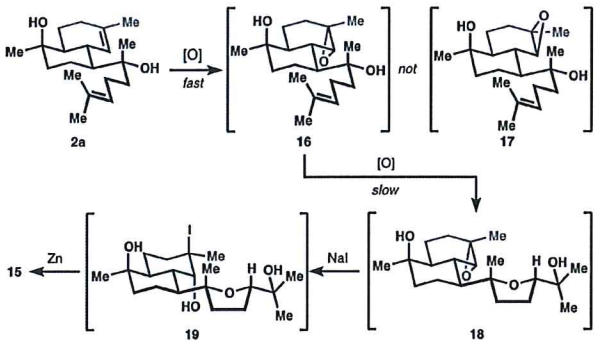


Figure 2. Stereoselective oxidative cyclization to **15**.

same conditions also mediated a slower, but stereoselective (93:7 d.r.) epoxidation of the side-chain alkene, as well as concomitant 5-*exo*-tet cyclization to the targeted tetrahydrofuran, whereas the A-ring epoxide was spared attack. Consequently, a sodium iodide/zinc metal-mediated epoxide deoxygenation selectively removed the unwanted ring epoxide, whereas the C14,15 oxidation was retained as the incipient hydroxy-tetrahydrofuran (see Figure 2).

The full kalihinol skeleton and correct oxidation state were thus established in eight steps from heterodendralene **5**; we next investigated elaboration to a known metabolite. Elimination of the exocyclic tertiary alcohol was effected by selective trifluoroacetylation and *syn*-elimination via thermolysis since ionizing conditions resulted in hydride shift from the tetrahydrofuran methine. In the same flask, we trifluoroacetylated the remaining alcohol and then installed the B-ring equatorial *tert*-alkyl isonitrile with our solvolytic stereoinversion.[8] The logic leading to this route (Scheme 2) requires some discussion.

We had originally targeted a tandem epoxide opening/trifluoroacetate stereoinversion of **20** (Figure 3) using our solvolysis conditions to install the bis-isonitrile motif. This approach was reported by Vanderwal to be successful, but low-yielding in his kalihinol B synthesis.[9e] We similarly found that this tandem reaction yielded only small amounts of the bis-isonitrile **21** (5–6%). The basis of the low yield was not the epoxide opening step, which was efficient and regioselective in substrate **20**. Instead, the subsequent B-ring stereoinversion[8] was low-yielding by virtue of competitive elimination (**22**→**23**).[25] Because the epoxide opening occurred faster than trifluoroacetate ionization, and the resulting isocyanohydrin caused elimination in ring B, we concluded that the B-ring C–N bond must be in place prior to epoxidation.

We were dismayed to find that the B-ring functional groups influenced the course of epoxide ionization. As shown in Table 2, the B-ring axial trifluoroacetate and alcohol led to **A** with high selectivity, whereas the equatorial isonitrile or formamide skewed the ratio to favor substantial quantities of regioisomers **B** and **C**, as well as semipinacol product **D**.[26] So, the A- and B-

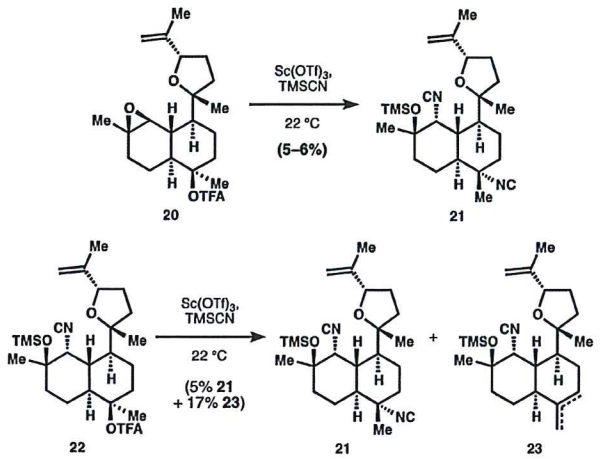
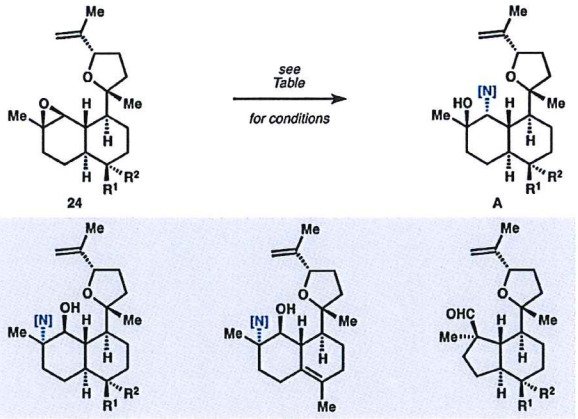


Figure 3. Tandem isonitrile formation is very low yielding.

Table 2. Isocyanohydrin Installation[a]



R^1/R^2	conditions [N]	R^1/R^2	A:B:C:D
OTFA/Me	TMSCN, $Sc(OTf)_3$ [NC]	OTFA/Me	83:0:17:0
OH/Me	TMSCN, $Sc(OTf)_3$ [NC]	OTMS/Me	100:0:0:0
Me/NC	TMSCN, $Sc(OTf)_3$ [NC]	Me/NC	61:0:39:0
Me/NHCHO	TMSCN, $Sc(OTf)_3$ [NC]	Me/NHCHO	54:31:0:15
Me/NC	NH_3, MeOH [NH_2]	Me/NC	100:0:0:0

[a]Any silylethers were converted to alcohols with TBAF.

ring substituents proved mutually incompatible in the tandem solvolysis sequence reported by Vanderwal.[9e]

Consequently, we relied on a simple but effective aminolysis to generate regioselectively the requisite A-ring functionality (Scheme 2 and Table 2, entry 5). First, chemoselective oxidation of the alkene of **25** occurred in preference to the isonitrile if carried out with dimethyldioxirane (DMDO) in the strongly hydrogen bond-donating solvent HFIP, which we posit deactivates the isonitrile against oxidation (Scheme 2). Aminolysis in methanol cleanly opened the epoxide to deliver a *sec*-alkyl amino *tert*-alcohol,[27] which was converted to the isocyanohydrin of **1** via difluorocarbene derived from difluoromethyl triflate[28] and KO*t*-Bu. More orthodox methods for amine to isonitrile conversion worked poorly: chloroform/sodium hydroxide[29] generated appreciable amounts of a dichlorocyclopropane and an amide; formylation of the hindered amine occurred slowly due to buildup of acid (isonitriles are produced by subsequent formamide dehydration).[30] Our alternative use of

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difluorocarbene for isonitrile synthesis therefore offers some advantages over existing methods, especially when multiple functional groups are present or the amine is hindered. This three-step procedure provides an efficient, stereo- and chemoselective strategy to install the kalihinol A-ring isocyanohydrin motif.

In summary, we have demonstrated a concise route to access the kalihinol (bifloran) ICTs via a putative biosynthetic intermediate, protokalihinol (**2a**), that we anticipate can be divergently advanced to the natural series of metabolites. The synthesis compares favorably to the current best approach to the kalihinols by Vanderwal: it is longer in total step count (17 vs 12), but higher in yield by one order of magnitude (1.3% vs 0.13%). The higher efficiency derives from solutions to stereochemical and chemoselectivity problems raised by prior work, but left unsolved. Some of these solutions include (1) a method to synthesize the kalihinol stereotetrad using an iterative cycloaddition of the new building block, "heterodendralene" **5**; (2) an alkoxide-directed isomerization method to access the thermodynamically disfavored $\Delta^{3,4}$ unsaturated *trans*-bifloran skeleton found throughout the diterpene class, and (3) a short, high-yielding, regio- and stereoselective strategy for installing the A-ring isocyanohydrin motif, including difluorocarbene-mediated isonitrile synthesis. This short and divergent route from protokalihinol **2a** allowed us to generate several analogs related to the metabolite series. We are currently using these compounds to interrogate the antiplasmodial activity and mechanism(s) of the kalihinol class.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/jacs.7b01124.

Data for $C_{19}H_{26}O_4$ (CIF)

Detailed experimental procedures, spectral data, chromatograms, and X-ray crystallography (PDF)

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Notes

The authors declare no competing financial interest.

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Physical-Chemistry cume

Notation:

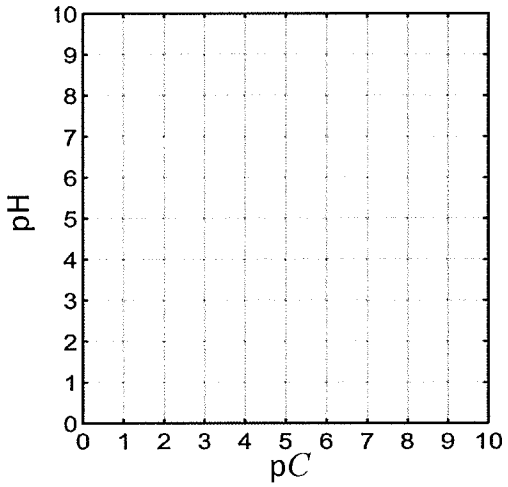
C: Acid concentration

pC = -log(C) ; for example, pC = 1.0 for a 0.10M solution.

pK_a = -log(K_a), where K_a is the equilibrium constant for acid dissociation in water.

pK_w = 14, for water dissociation.

Before starting: Please use a full page to draw a square plot of pH vs. pC, like the one below. The Y-axis should be labeled pH and run from 0 to 10. The X-axis should be labeled pC and also run from 0 to 10. Draw a grid line at every unit of pH and pC:



1. ***Diluting a strong monoprotic acid***

(Use filled circles, ●, to indicate your answers on the pH vs. pC plot).

(a) What is the pH of a 0.10M solution of HCl in water? Add your answer on the plot.
[5 points]

(b) Now dilute the solution of part (a) by a factor of a thousand, so that pC = 4.0. Calculate the pH of the resulting solution and indicate it on your plot.
[10 points]

(c) Now dilute the solution of part (b) by another factor of a thousand. Calculate the pH of the resulting solution and indicate it on your plot.
[10 points]

(d) Draw a continuous solid line for the entire range of pC from 0 to 10. If you trust your previous three answers, the line should pass through those points.
[5 points]

2. **Diluting a weak monoprotic acid of pK_a = 4.76** (This is the value for acetic acid).
(Use open circles, **O** , to indicate your answers on the pH vs. pC plot).

(a) What is the pH of a 0.10M solution of acetic acid in water? Add your answer on the plot.
[10 points]

(b) Now dilute the solution of part (2a) by a factor of a thousand, so that pC = 4.0. Calculate the pH of the resulting solution, and indicate it on your plot.
[10 points]

(c) Now dilute the solution of part (2b) by another factor of a thousand. Estimate the pH of the resulting solution, and indicate it on your plot.
[10 points]

(d) Draw a dashed line for the entire range of pC from 0 to 10. If you trust your previous three answers, the line should pass through those points.
[5 points]

(e) To calculate the answer to part (2c) correctly to two significant figures, you would need to find the real solutions of a cubic equation of the type:

$$x^3 + ax^2 + bx + d = 0$$

If x represents the concentration of hydronium ions, please provide expressions for the coefficients a, b, and d in terms of K_a, K_w, and C.
[30 points]

(f) Sketch your best guess for the percent dissociation of the acid vs. pC. The X-axis should be pC from 0 to 10. The Y-axis should be %dissociation of the acid from 0 to 100. Why is acetic acid referred to as a "weak acid" ?
[5 points]

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.)