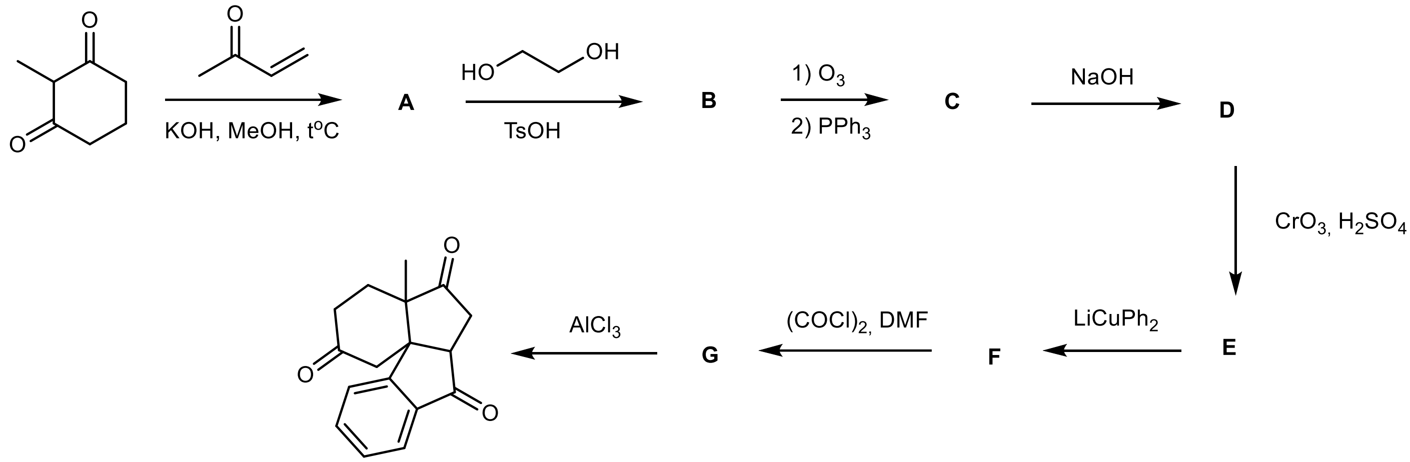
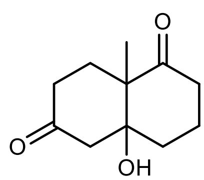
CCO Problem Set #5. Ultimate Boss. **Date: Feb 1, 2025**

Questions 1-7 should be solved together.

In the following scheme, find the structural formulas of compounds **A**-**G**:



1. Choose the correct structural formula of **A**.

a.


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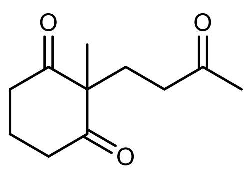
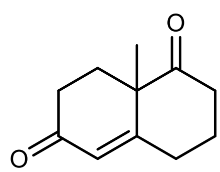
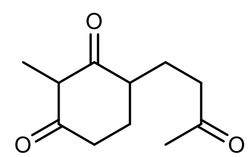
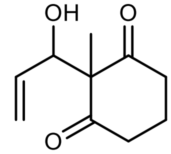
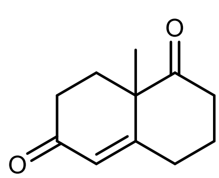


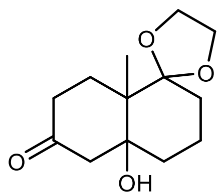
c.


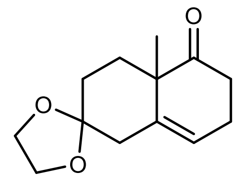
d.


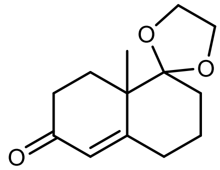
e.


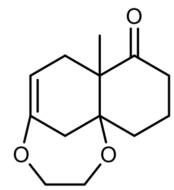
2. Choose the correct structural formula of **B**.

a.


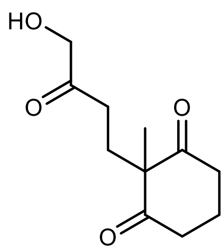
b. 

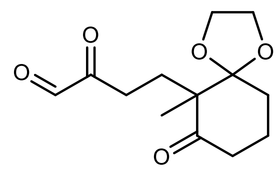
d. 

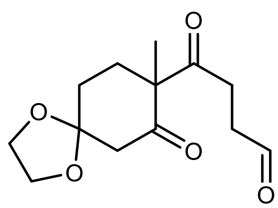
c. 

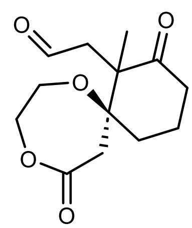
e. 

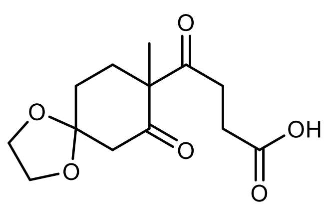
3. Choose the correct structural formula of **C**.

a. 

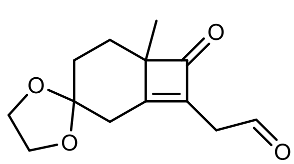
d. 

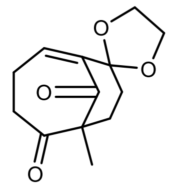
b. 

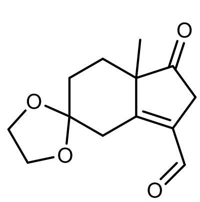
e. 

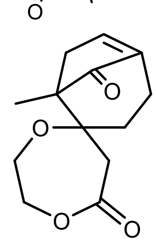
c. 

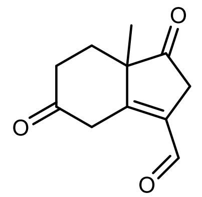
4. Choose the correct structural formula of **D**.

a. 

c. 

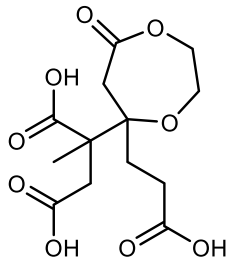
b. 

d. 



e.

5. Choose the correct structural formula of **E**.

a.


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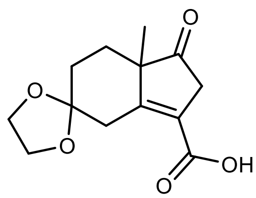

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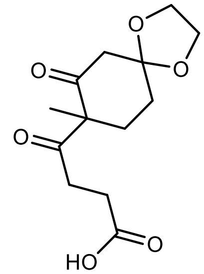

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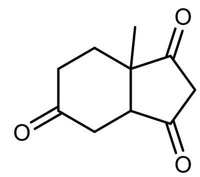
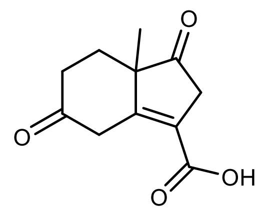
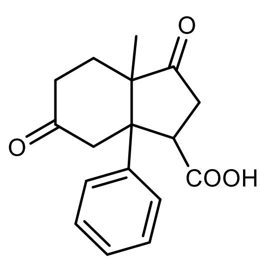


e.


6. Choose the correct structural formula of **F**.

a.


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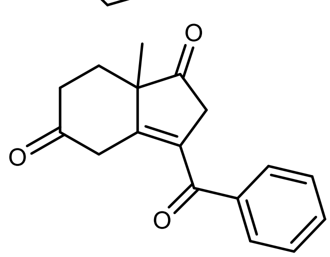

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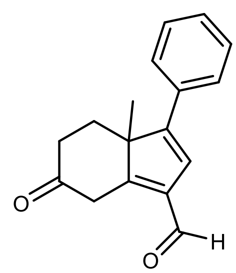

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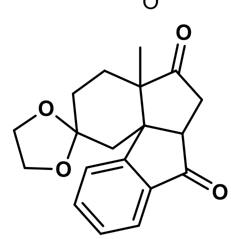
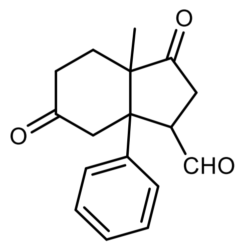
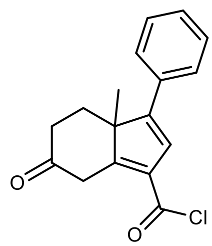
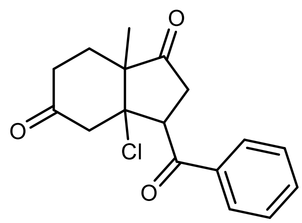
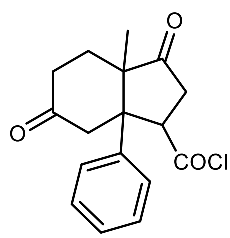


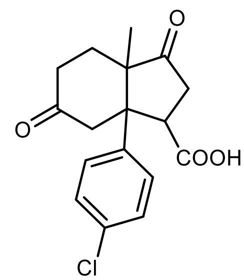
e. 

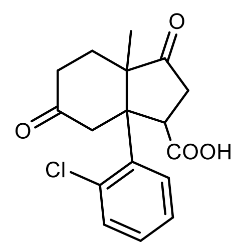
7. Choose the correct structural formula of **G**.

a. 

b. 

c. 

d. 

e. 

Questions 8-13 should be solved together.

The ozone layer in the Earth's atmosphere is a natural filter that absorbs dangerous ultraviolet radiation from the Sun before it reaches the Earth's surface. A decrease in the ozone content in the atmosphere can lead to dangerous consequences for life on Earth. Ozone is found mainly in the stratosphere at an altitude of 15 to 50 km, with a maximum concentration at an altitude of about 25 km.

In 1930, British scientist Sydney Chapman proposed a mechanism for the formation of atmospheric ozone, consisting of four reactions (Chapman mechanism):

$$1.\ O_2 + h\nu \xrightarrow{k_1} 2O$$

$$2.\ O + O_2 + M \xrightarrow{k_2} O_3 + M$$

$$3.\ O_3 + h\nu \xrightarrow{k_3} O + O_2$$

$$4.\ O_3 + O \xrightarrow{k_4} 2O_2$$

The absorption of ultraviolet radiation in reaction 3 explains the protective properties of the ozone layer. The molecule M can be any molecule in the atmosphere.

As a result of these processes, a steady state is established, and the ozone concentration in the atmosphere is maintained approximately constant. The ozone content in the stratosphere varies depending on latitude and time of year, but on average does not exceed several parts per million (ppm). Although this concentration seems small, it is sufficient to block 95–98% of the sun's ultraviolet radiation.

Data:
$k_1 = 3\cdot10^{12}\ s^{-1}$, $k_2 = 1.2\cdot10^{-33}$ (units?), $k_3 = 5.5\cdot10^{-4}\ s^{-1}$, $k_4 = 6.9\cdot10^{-16}$ (units?).
The concentration [M] at an altitude of 25 km is approximately 10^{18} molecules$\cdot$cm^{-3}.

8. What are the correct units for k_2 and k_4 correspondingly?

a. $cm^6\cdot molecules^{-2}\cdot s^{-1}$; $cm^3\cdot molecules^{-1}\cdot s^{-1}$
b. $cm^6\cdot s^{-2}$; $cm^3\cdot s^{-1}$
c. $cm^3\cdot molecules^{-1}\cdot s^{-1}$; $cm^3\cdot molecules^{-1}\cdot s^{-1}$
d. $M^{-2}\cdot s^{-1}$; s^{-1}
e. $cm^3\cdot molecules^{-1}\cdot M^{-1}\cdot s^{-1}$; $M\cdot s^{-1}$

9. Calculate the maximum wavelength of sunlight capable of causing the dissociation of oxygen molecules according to reaction 1 if the bond energy in an oxygen molecule is 498 kJ/mol.

a. 240 nm
b. 332 nm
c. 450 nm
d. 686 nm
e. 1045 nm

10. What, in your opinion, is the most likely candidate for the role of M? Write down its chemical formula.

11. Derive an expression for $[O_3]$ as a function of rate constants, [M], and $[O_2]$. What is the dependence of $[O_3]$ on $[O_2]$ at low concentrations of $[O_2]$?

a. $[O_3]$ is independent of $[O_2]$
b. linear dependence
c. quadratic dependence
d. $[O_3]$ is proportional to $[O_2]^{3/2}$
e. exponential dependence

12. Calculate the ratio of O_3 to O_2 at 25 km altitude.

a. $7.9 \cdot 10^{-8}$
b. $4.3 \cdot 10^{-7}$
c. $6.6 \cdot 10^{-6}$
d. $2.7 \cdot 10^{-6}$
e. $9.7 \cdot 10^{-5}$

13. What is the dependence of $[O_3]$ on $[O_2]$ if the same reactions are conducted in pure oxygen instead of air?

a. $[O_3]$ is independent of $[O_2]$
b. linear dependence
c. quadratic dependence
d. $[O_3]$ is proportional to $[O_2]^{3/2}$
e. exponential dependence

Questions 14-16 should be solved together.

To prepare a pyrophoric metal nanopowder, a solid diprotic acid **A** containing 32% carbon and a colourless powder **B** (containing 4.5% carbon) were used. **B** decomposes in acidic conditions releasing a gas with a density of 1.97 g/L at STP.

The reaction of **A** with **B** yielded a solution from which crystals of substance **C** precipitated upon standing. They are colourless and very poorly soluble in water, and their solution produces a black precipitate upon treatment with hydrogen sulphide and a dark brown precipitate upon mixing with sodium hypochlorite solution. The black precipitate turns white if treated with hydrogen peroxide.

Heating substance **C** to 400 °C in a vacuum yielded metal nanopowder **D** with a particle size of 50 nm. In air, **D** gradually turns into a red-orange powder **E** containing 8.2% oxygen.

14. Write the chemical symbol of the metal **D**.

15. Write the chemical formula of **C**.

16. Write the chemical formula of **E**.

17. When a certain gas decomposes upon heating, the volume of the products is 1.5 times greater than the volume of the original gas, and the hydrogen density of the decomposition products is 11.67 less than the hydrogen density of the original gas. Write the chemical formula of the initial gas.

Questions 18-21 should be solved together.

In the following reactions **X**, **Y**, **Z**, and **A** are elements of the periodic table.

$XY_2Z + A_2 = XZA_3 + Y_2$
$Y_2 + Z = Y_2Z_2$
$X + Z = XZ_2$
$Y_2Z_2 + A_2 = Y_2 + ZA_2$
$XZ_2 + Y_2 = XY_2Z + Z$
$X + ZA_2 = XA + ZA$

$Y_2Z_2 + X = XY_2Z_2$
$X + Y_2 = X_3Y_2$

18. Write the chemical symbol of the element **X**.

19. Write the chemical symbol of the element **Y**.

20. Write the chemical symbol of the element **Z**.

21. Write the chemical symbol of the element **A**.

22. Match the pairs of values of the parameters of the Arrhenius equation A – E (kJ/mol) with the reaction equations.

a) $2CH_3 \rightarrow C_2H_6$
b) $2C_2H_5 \rightarrow C_4H_{10}$
c) $C_2H_4 + H_2 \rightarrow C_2H_6$
d) $CH_3CH{=}CHCH_3 + HBr \rightarrow C_4H_9Br$
e) $C_2H_5Cl \rightarrow C_2H_4 + HCl$

I. $1.6{\cdot}10^{10} – 94.2$
II. $4{\cdot}10^{4} – 247.5$
III. $1{\cdot}10^{4} – 0$
IV. $4{\cdot}10^{13} – 180.5$
V. $1.1{\cdot}10^{4} – 8.4$

Questions 23-24 should be solved together.

Sulfuric and hydrochloric acids are mixed in an aqueous solution (this mixture is used to dissolve some ores). The mixture has a pH of 0.00. After 100x dilution, the pH of the mixture was 1.92. The basicity constant of the sulfate ion $K_b = 8.33{\cdot}10^{-13}$.

In answering the following questions use scientific exponential notation and take one significant figure. For example, K_b (above) would have been written as 8e-13.

23. Write the concentration (mol/L) of sulfuric acid.

24. Write the concentration (mol/L) of hydrochloric acid.

Questions 25-30 should be solved together.

In 1912, Alfred Werner synthesized several isomeric cobalt complex compounds, which served as good evidence for the correctness of his theory of the structure of complex compounds.

Air was passed through a solution of 10 g $CoCl_2{\times}6H_2O$ in 150 g 10% aqueous ethylenediamine ($H_2N\text{-}CH_2\text{-}CH_2\text{-}NH_2$, en) for several hours. The brown solution was acidified with hydrochloric acid and evaporated until crystallization began, then ammonium nitrate was added to the mother liquor and a small amount of green lamellar crystals was formed (substance **A**). The precipitate was filtered off, and NaBr was added to the filtrate, which resulted in the formation of a large amount of needle-like yellow-orange crystals (substance **C**).

An aqueous solution containing 100 g of substance **C** was treated with silver tartrate in an amount necessary to precipitate two equivalents of halide ions (68.3 g of silver tartrate are added). The silver halide precipitate was separated by filtration, and the solution was evaporated. The D-tartrate crystallized during evaporation is filtered off (substance **D**), and the cooled filtrate is transformed into a gelatinous mass containing L-tartrate (substance **E**).

Suspensions of crystals **D** and **E** separately were ground in mortars with slightly heated conc. HBr. The precipitates in both cases are separated by filtration and recrystallized from hot water (substances **F** and **G**, respectively). The properties of the obtained substances are presented in the table.

Compound	Mass fraction, %			Colour	Molar conductivity	$[\alpha]_{D\ (1\ \%)}$
	Co	N	Br(Cl)			
A	18.89	22.44	(22.72)	green	105	-
B	18.89	22.44	(22.72)	purple	107	-
C	11.06	15.77	44.97	yellow	415	-
D	10.58	15.08	14.34	yellow	265	+98°
E	10.58	15.08	14.34	yellow	273	-
F	11.44	16.32	46.54	yellow	420	+117°
G	11.44	16.32	46.54	yellow	418	-115°

For the following questions, tartrate should be written as (C4H4O6), ethylenediamine as en.

25. Write the chemical formula of **A**.

26. Write the chemical formula of **C**.

27. Write the chemical formula of **D**.

28. Write the chemical formula of **F**.

29. Choose the type of isomerism observed in **A**/**B.**

a. ionization
b. coordination
c. linkage
d. optical
e. geometric

30. Choose the type of isomerism observed in **F**/**G.**

a. ionization
b. coordination
c. linkage
d. optical
e. geometric

Supporting Information

Arrhenius equation:

$$k = Ae^{-\frac{E_A}{RT}}$$

Energy of light:

$$E = h\nu = \frac{hc}{\lambda}$$

Planck's constant h = $6.626 \cdot 10^{-34}$ J·s,

Speed of light c = $2.998 \cdot 10^{8}$ $m \cdot s^{-1}$,

Avogadro's constant $N_A = 6.02 \cdot 10^{23}$ mol^{-1}.