Organic Chemistry 1

Real drugs and natural products, core Orgo 1 skills

The Scary Molecule Set

Big drugs, short questions

25 original problems with step-by-step solutions

Easy	8 problems. One idea at a time: a warm-up that builds the basic skill.
Exam	10 problems. The kind of multi-step question you can expect on a test.
Challenge	7 problems. Harder, combines several ideas; go slowly and show your work.

How to use this set

1. Open **Part A** and try each problem on paper first, before you look at any solution.
2. Then open **Part B**, check your answer in the yellow box, and read the numbered steps. If your answer differs, find the step where your reasoning and the solution part ways.
3. Redo any problem you missed a few days later, without looking.

USOrgo

Original practice problems written for Orgo 1 students. Not affiliated with any textbook publisher, university or exam body.

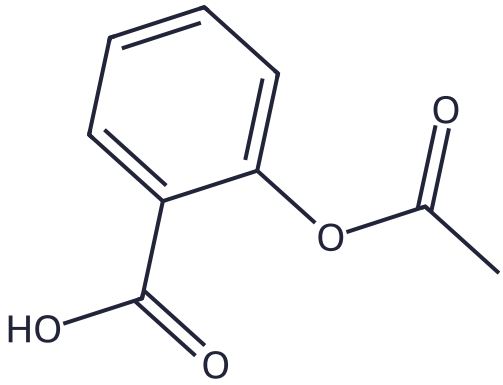
Part A Problems

Try each one first. No answers here.

Easy One idea at a time

1 Easy

A professor shows aspirin (acetylsalicylic acid): formula $C_9H_8O_4$.



professor shows aspirin

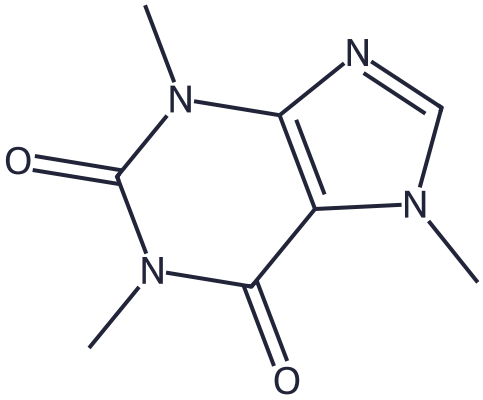
How many of its carbon atoms are sp^3, how many are sp^2, and how many are sp?

2 Easy

Caffeine has the formula $C_8H_{10}N_4O_2$. It contains two fused rings.

(a) Calculate the degrees of unsaturation from the formula alone.

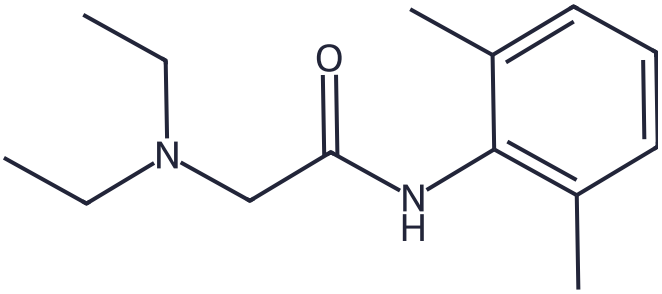
(b) Check that the answer matches the structure by listing what the 6 units are.



caffeine

3 Easy

Lidocaine: formula $C_{14}H_{22}N_2O$.

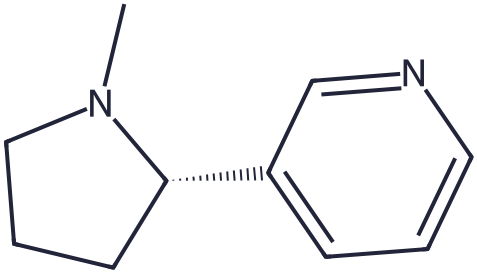


Lidocaine

Which of the following functional groups are present? (i) tertiary amine, (ii) secondary amide, (iii) ester, (iv) aromatic ring, (v) carboxylic acid, (vi) ether, (vii) ketone, (viii) primary amine.

4 Easy

Nicotine: formula $C_{10}H_{14}N_2$. It has two nitrogen atoms: one in the five-membered saturated ring (bearing a CH_3), one in the six-membered aromatic ring.

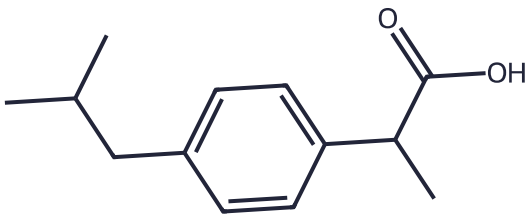


Nicotine

For each nitrogen give the hybridization, the number of lone pairs, and the molecular geometry around the N.

5 Easy

Ibuprofen: formula $C_{13}H_{18}O_2$.



Ibuprofen

Three protons are labeled: Ha is the O-H of the carboxylic acid group; Hb is a C-H on the benzene ring; Hc is a C-H of one of the CH_3 groups of the isobutyl group.

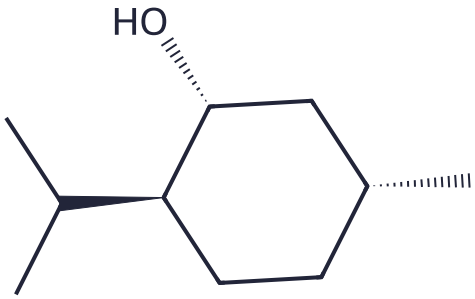
Rank them from most acidic to least acidic and state the reason for each comparison.

6 Easy

Menthol: formula $C_{10}H_{20}O$. The ring carries three substituents: OH, isopropyl and CH_3.

(a) How many stereocenters does menthol have?

(b) What is the maximum number of stereoisomers?



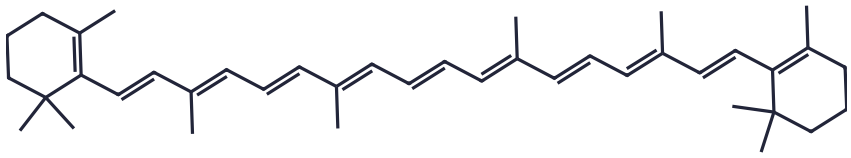
Menthol

7 Easy

Beta-carotene (the orange pigment in carrots): formula $C_{40}H_{56}$.

(a) Is beta-carotene polar or nonpolar overall? Does it have a significant molecular dipole moment?

(b) Is it expected to dissolve better in water or in hexane? Can it hydrogen-bond with water?

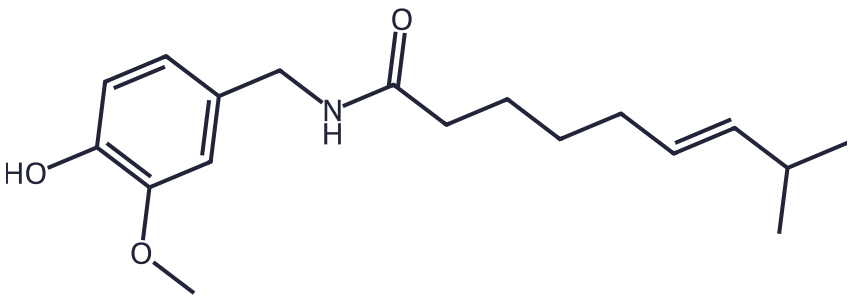


carrots

8 Easy

Capsaicin (the hot compound in chili peppers): formula $C_{18}H_{27}NO_3$. It has one ring.

(a) How many sigma bonds? (b) How many pi bonds? (c) Is the drawn C=C bond E or Z?



chili peppers

Part B Worked solutions

Check your answer in the yellow box, then read the steps.

Easy — One idea at a time

1 Easy

Hybrid, Count

Answer 1 sp^3, 8 sp^2, 0 sp.

Solution

1. Go carbon by carbon and ignore the oxygens; only the nine C atoms matter.
2. The CH_3 of the acetyl group has four single bonds: sp^3. That is the only sp^3 carbon.
3. Each of the six benzene-ring carbons has a double bond (or aromatic pi bond) and three sigma bonds: sp^2.
4. The ester C=O carbon and the carboxylic acid C=O carbon each have one double bond: sp^2.
5. Total: 1 + 6 + 2 = 9 carbons, so 1 sp^3, 8 sp^2, 0 sp.
6. Common panic mistake: trying to decide the hybridization of the whole molecule. You do not need the whole molecule: look only at the number of pi bonds on each carbon (0 pi bonds = sp^3, 1 = sp^2, 2 or a triple bond = sp).

2 Easy

DoU

Answer (a) 6. (b) 2 rings + 2 C=O + 1 C=C + 1 C=N = 6.

Solution

1. Use DoU = (2C + 2 + N - H - X) / 2 with C = 8, N = 4, H = 10, X = 0 (oxygen is ignored).
2. DoU = (16 + 2 + 4 - 10) / 2 = 12 / 2 = 6.
3. In the drawn structure: the five-membered ring and the six-membered ring are 2 rings; the two C=O groups are 2 pi bonds; the ring C=C and C=N in the five-membered ring are 2 more pi bonds. Total 6.
4. Common panic mistake: adding N atoms to the hydrogens instead of the carbons. Each N adds 1 to the numerator and O does nothing. You do not need the structure at all for part (a): look only at the formula.

3 Easy

FG

Answer (i) (ii) and (iv) only.

Solution

1. Scan only for heteroatoms. There are just three: two N atoms and one O.
2. The O is a C=O attached to an N on one side and a carbon on the other: that is an amide, and the N has one H and one aryl group, so it is a secondary amide. No second O means no ester, acid or ether.
3. The other N has three carbon substituents (two ethyl, one CH_2): tertiary amine.
4. The six-membered ring with alternating double bonds is an aromatic ring (benzene ring).
5. A ketone would need a C=O with carbons on both sides; here one side is N, so it is not a ketone. There is no NH_2, so no primary amine.
6. Common panic mistake: calling the amide N "an amine". The amide N is bonded to a C=O carbon, so it belongs to the amide functional group.

4 Easy

Hybrid, VSEPR, Count

Answer Five-membered-ring N: sp^3, 1 lone pair, trigonal pyramidal. Aromatic-ring N: sp^2, 1 lone pair, bent (two substituents, about 117 degrees at N in a planar ring).

Solution

1. Pyrrolidine-type N: three sigma bonds (CH_3, two ring carbons) plus 1 lone pair = 4 electron domains: sp^3, tetrahedral electron geometry, trigonal pyramidal molecular geometry.
2. Pyridine-type N: it is in a flat aromatic ring. It has two sigma bonds (to the two neighboring ring carbons), one pi bond in the ring, and one lone pair = 3 sigma/lone-pair domains: sp^2.
3. That lone pair lies in the plane of the ring in an sp^2 orbital, not in the ring pi system, so there is exactly 1 lone pair on each N.
4. The molecular geometry (atoms only) at the pyridine-type N is bent, with a C-N-C angle of about 117 degrees.
5. Common panic mistake: trying to describe the shape of the whole molecule. You do not need the whole molecule: look only at the atoms bonded to each N and count the electron domains.

5 Easy

Acid, ARIO

Answer Ha > Hb > Hc.

Solution

1. Use ARIO (Atom, Resonance, Induction, Orbital): compare the atom that holds the negative charge in the conjugate base first.
2. Ha: conjugate base has the charge on O, a more electronegative atom than C, and it is resonance-stabilized over two oxygens (carboxylate). pKa about 4.5.
3. Hb and Hc both give a carbanion (charge on C), so Ha wins by the Atom rule: Ha is by far the most acidic.
4. Hb versus Hc: orbital. The aromatic C-H carbon is sp^2 (33 percent s), so the lone pair of the carbanion sits closer to the nucleus than in the sp^3 CH_3 carbon (25 percent s). pKa about 43 versus about 50.
5. Order: Ha (pKa 4.5) > Hb (about 43) > Hc (about 50).
6. Common panic mistake: worrying about the 13 carbons. You do not need the whole molecule: look only at the atom that carries the charge after each proton leaves.

6 Easy

Stereo

Answer (a) 3. (b) 8.

Solution

1. A stereocenter is an sp^3 carbon with four different groups. Check only the ring carbons that carry a substituent.
2. The carbon bearing OH has OH, H, and two different ring paths (one leads toward the isopropyl-bearing carbon, the other toward the CH_2 and the methyl-bearing carbon): stereocenter.
3. The carbon bearing isopropyl: isopropyl, H, and two different ring paths: stereocenter.
4. The carbon bearing CH_3: CH_3, H and two different ring paths: stereocenter. (The paths are different because the other two substituents are not symmetrically placed.)
5. The isopropyl CH is bonded to two identical CH_3 groups, so it is not a stereocenter. The other ring CH_2 carbons have two H and are not stereocenters.
6. Maximum stereoisomers = 2^3 = 8 (no internal symmetry, so no meso reduction).
7. Common panic mistake: marking every ring carbon. Only carbons with four different groups count.

7 Easy

Polar, HBond

Answer (a) Nonpolar; net dipole essentially zero. (b) Hexane. It has no O-H or N-H and no lone pairs, so it can neither donate nor accept hydrogen bonds.

Solution

1. Read the formula, not the picture: $C_{40}H_{56}$ contains only carbon and hydrogen.
2. C-H and C-C bonds are essentially nonpolar (electronegativity difference between C and H is about 0.4, and there are no heteroatoms).
3. The molecule is a long, almost symmetric hydrocarbon, so there is no region of significant partial charge and no net dipole.
4. For hydrogen bonding you need an H on N, O or F (donor) and a lone pair on N, O or F (acceptor); beta-carotene has neither, so it is insoluble in water.
5. Like dissolves like: a nonpolar hydrocarbon dissolves in the nonpolar solvent hexane (and in fats and oils).
6. Common panic mistake: counting the 11 double bonds as "polar functional groups". Alkenes do not create a significant dipole.

8 Easy

Count, Stereo

Answer (a) 49. (b) 5. (c) E.

Solution

1. Count atoms from the formula: 18 C + 27 H + 1 N + 3 O = 49 atoms.
2. Sigma bonds in any single-ring molecule = (number of atoms - 1) + number of rings = 48 + 1 = 49. (Every double or triple bond contributes exactly one sigma bond; the extra bonds are pi.)
3. DoU = (36 + 2 + 1 - 27) / 2 = 6. One of the 6 is the ring, so pi bonds = 6 - 1 = 5: three in the benzene ring, one C=O, one C=C.
4. For E/Z at the C=C: each alkene carbon has one H and one carbon group (the CH_2 chain on one side, the isopropyl on the other). The carbon groups outrank H, and they sit on opposite sides in the drawing (the "/.. /" pair means trans), so the isomer is E.
5. Common panic mistake: counting bonds one by one on the picture. You do not need the whole molecule: use the formula and the ring count.