Organic Chemistry 1

SN2, SN1, E2 and E1

Chapter 7

Alkyl Halides: Substitution and Elimination

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

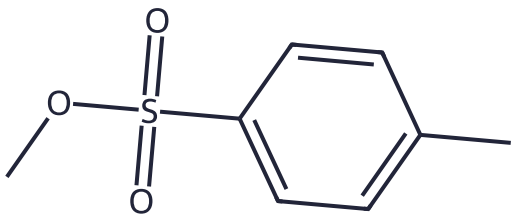
1 Easy

In methanol (a polar protic solvent), rank the halide ions from the strongest to the weakest nucleophile, and give the main reason.

Species: iodide, bromide, chloride, fluoride.

2 Easy

Rank these leaving groups from best to worst: bromide, chloride, water (leaving from a protonated alcohol, R-OH_2^+), hydroxide, amide ion. Then explain in one or two sentences why converting an alcohol to its tosylate (for example methyl tosylate an R-OTs) turns OH into a good leaving group.



its tosylate (for example methyl tosylate)

3 Easy

1-Bromobutane reacts with sodium azide in DMF at room temperature to give 1-azidobutane.

(a) Identify the mechanism and write the rate law.

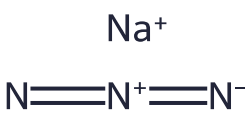
(b) What happens to the rate if [azide] is tripled?

(c) What happens to the rate if [1-bromobutane] is doubled and [azide] is halved?

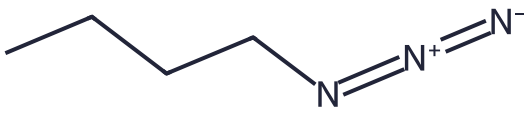
(d) Describe the curved arrows.



1-bromobutane



sodium azide



1-azidobutane

4 Easy

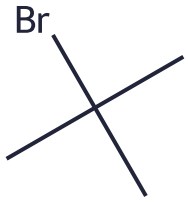
Tert-butyl bromide is dissolved in methanol at 25 degrees C.

(a) Name the mechanism and give the rate law.

(b) Describe the energy diagram: how many transition states and intermediates, and which transition state is highest?

(c) Give the major substitution product and the minor elimination product.

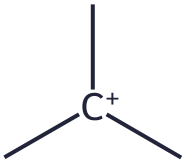
(d) Rank these carbocations from most to least stable:



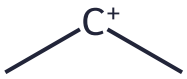
tert-butyl bromide



methanol



(d)

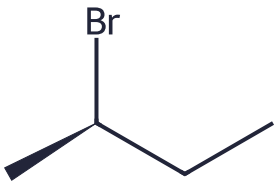






5 Easy

(R)-2-Bromobutane is treated with sodium cyanide in DMSO. Give the product, including its configuration, and explain.



–2-Bromobutane



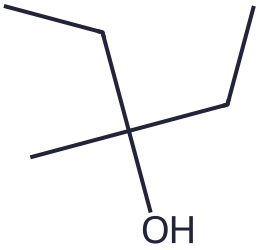
sodium cyanide

6 Easy

Predict the product of each reaction and name the mechanism.

(a) 3-Methylpentan-3-ol + concentrated HBr.

(b) Butan-1-ol + HBr with H_2SO_4, heat.



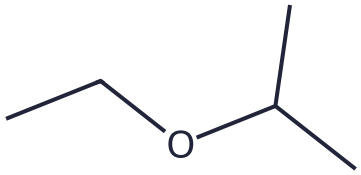
(a) 3-methylpentan-3-ol



(b) butan-1-ol

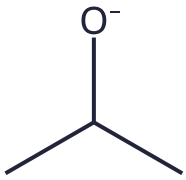
7 Easy

Choose the better route to ethyl isopropyl ether (2-ethoxypropane):

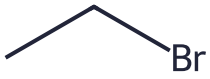


ethyl isopropyl ether (2-ethoxypropane)

Route 1: sodium isopropoxide + bromoethane.

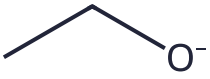


sodium isopropoxide

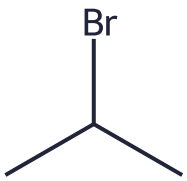


bromoethane

Route 2: sodium ethoxide + 2-bromopropane.



sodium ethoxide



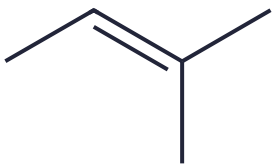
2-bromopropane

Name the mechanism and the main by-product of the poorer route.

8 Easy

(a) Rank by stability, most stable first: 2-methylbut-2-ene; pent-1-ene; (E)-pent-2-ene; (Z)-pent-2-ene.

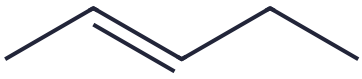
(b) 2-Bromo-2-methylbutane is heated with sodium ethoxide in ethanol. Give the major E2 product.



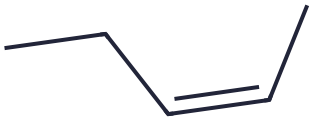
(a) 2-methylbut-2-ene



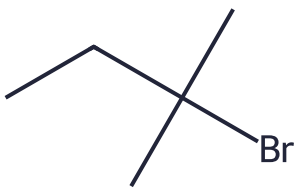
pent-1-ene



(E)-pent-2-ene



(Z)-pent-2-ene



(b) 2-bromo-2-methylbutane

Exam *Test-level, multi-step*

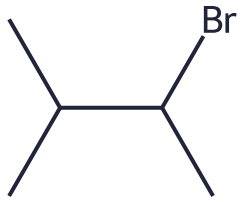
9 Exam

2-Bromo-3-methylbutane is warmed in ethanol with no added base.

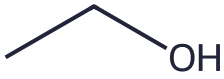
(a) Name the mechanism(s) and rate law.

(b) Show the carbocation sequence.

(c) Give the major substitution product and one elimination product.



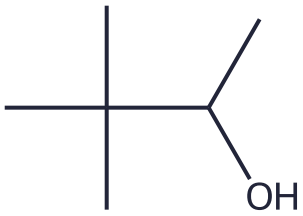
2-bromo-3-methylbutane

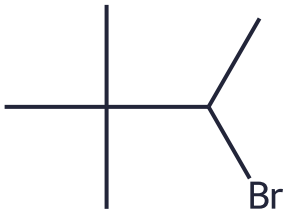


ethanol

10 Exam

3,3-Dimethylbutan-2-ol is treated with concentrated HBr. Give the major product and the mechanism, and explain why 2-bromo-3,3-dimethylbutane is not the major product.





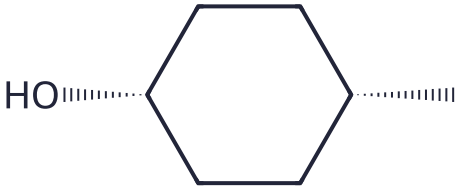
3,3-dimethylbutan-2-ol

11 Exam

cis-4-Methylcyclohexan-1-ol is treated with (1) TsCl, pyridine, then (2) sodium azide in DMSO.

(a) Give the intermediate and final product with stereochemistry.

(b) State what happens to the configuration at carbon in each step.



cis-4-Methylcyclohexan-1-ol

12 Exam

4-Bromobutan-1-ol is treated with one equivalent of sodium hydride in THF.

(a) Give the product and mechanism, and say what gas is evolved.

(b) Explain why the intramolecular reaction wins over intermolecular ether formation, even though the same functional groups are present in other molecules.



4-bromobutan-1-ol

13 Exam

Choose the better solvent (or the faster case) and explain in one sentence each.

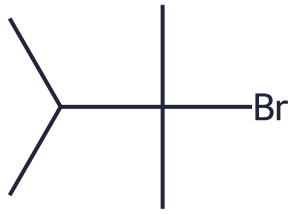
(a) Rate of 1-bromopropane + sodium cyanide: DMSO or methanol?

(b) Rate of solvolysis of tert-butyl chloride: ethanol or 1:1 ethanol/water?

(c) In DMSO, rank Cl^-, Br^-, I^- as nucleophiles toward CH_3-OTs, and compare with the order you gave in methanol.

14 Exam

2-Bromo-2,3-dimethylbutane is treated with (i) sodium ethoxide in ethanol, heat; (ii) potassium tert-butoxide in tert-butanol, heat. Give the major alkene in each case and explain.



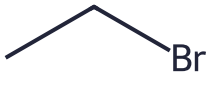
2-bromo-2,3-dimethylbutane

15 Exam

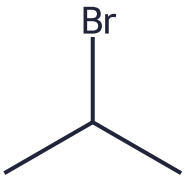
Rank these in order of decreasing rate of SN2 reaction with sodium iodide in acetone: bromomethane; bromoethane; 2-bromopropane; 1-bromo-2,2-dimethylpropane (neopentyl bromide). State what happens with 2-bromo-2-methylpropane.



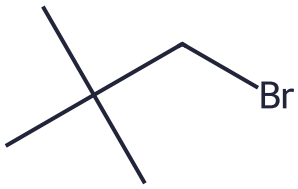
bromomethane



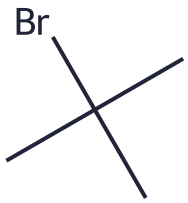
bromoethane



2-bromopropane



1-bromo-2,2-dimethylpropane (neopentyl bromide)



2-bromo-2-methylpropane

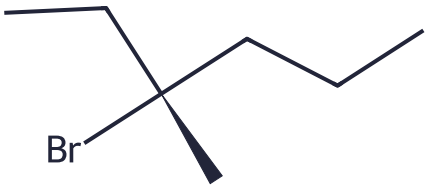
16 Exam

(R)-3-Bromo-3-methylhexane is dissolved in methanol.

(a) Name the mechanism and give the substitution product(s) with stereochemistry.

(b) Will the product mixture be optically active? Explain.

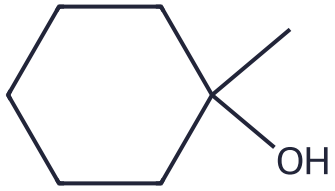
(c) Name two elimination products.



–3-Bromo-3-methylhexane

17 Exam

1-Methylcyclohexan-1-ol is treated separately with (i) concentrated HBr at 0 degrees C; (ii) concentrated H_2SO_4 with heating. Give the major organic product in each case and explain the difference.



1-methylcyclohexan-1-ol

18 Exam

For each reaction give the dominant mechanism and the major organic product.

(a) 1-Bromobutane + $NaOCH_3$ in CH_3OH.

(b) 3-Bromo-3-ethylpentane + $NaOCH_2CH_3$ in ethanol, heat.

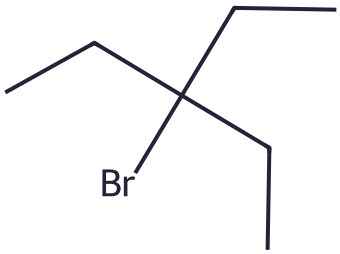
(c) 1-Iodopropane + NaN_3 in DMF.

(d) 2-Chloro-2-methylpropane in methanol, 25 degrees C.

(e) 2-Bromopropane + $NaOCH_2CH_3$ in ethanol, heat.



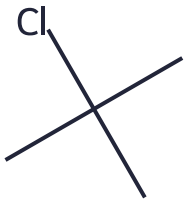
(a) 1-bromobutane



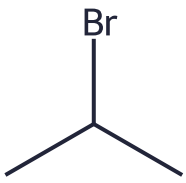
(b) 3-bromo-3-ethylpentane



(c) 1-iodopropane



(d) 2-chloro-2-methylpropane



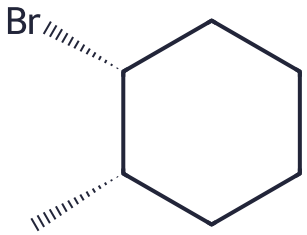
(e) 2-bromopropane

19 Challenge

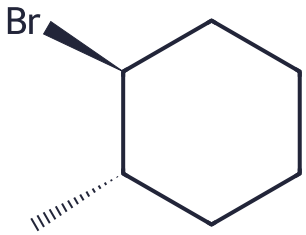
cis-1-Bromo-2-methylcyclohexane (racemic, one enantiomer shown) and trans-1-bromo-2-methylcyclohexane (racemic) are each treated with sodium ethoxide in ethanol.

(a) Draw the chair needed for E2 in each case and identify the alkene formed.

(b) Which isomer reacts faster? Explain.



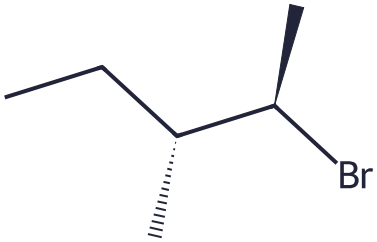
cis-1-Bromo-2-methylcyclohexane



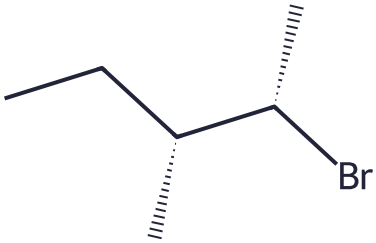
trans-1-bromo-2-methylcyclohexane

20 Challenge

Both (2R,3R)-2-bromo-3-methylpentane and (2S,3R)-2-bromo-3-methylpentane are treated with sodium ethoxide in ethanol. For each one, draw the Newman projection along C2-C3 in the reactive conformation and give the major alkene, including E or Z.



(2R,3R)-2-bromo-3-methylpentane



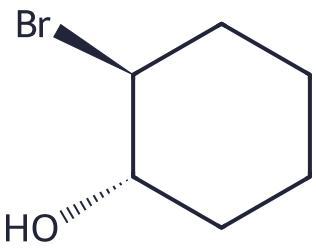
(2S,3R)-2-bromo-3-methylpentane

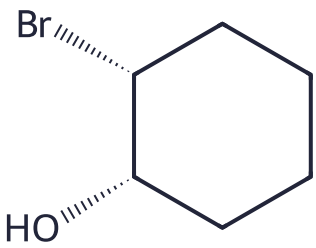
21 Challenge

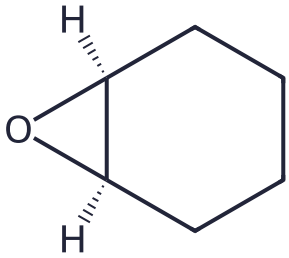
Each of the two bromohydrins below is treated with aqueous NaOH. trans-2-Bromocyclohexan-1-ol: cis-2-Bromocyclohexan-1-ol:

(a) Which one forms cyclohexene oxide readily? Draw the required chair.

(b) Why can the other not give the epoxide by the same path? Name the kind of reaction the epoxide-forming step is.



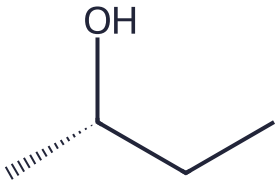




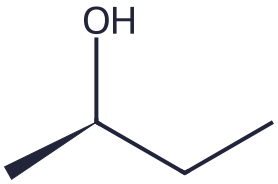
(a)

22 Challenge

Design a three-step conversion of (S)-butan-2-ol into (R)-butan-2-ol. Give the reagents, intermediates (with configurations), and explain why a one-step reaction with HBr or with NaOH on the tosylate would not be a good alternative.



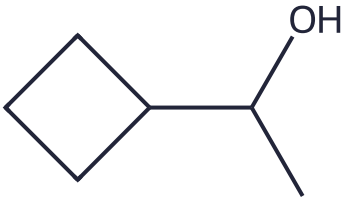
(S)-butan-2-ol



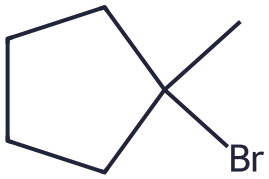
(R)-butan-2-ol

23 Challenge

1-Cyclobutylethan-1-ol is treated with concentrated HBr. The major product is 1-bromo-1-methylcyclopentane. Write the mechanism step by step, and explain why a cyclobutane ring is willing to expand.



1-cyclobutylethan-1-ol



1-bromo-1-methylcyclopentane

24 Challenge

A secondary alkyl bromide RBr reacts in aqueous ethanol containing NaOH at 25 degrees C. The initial rates are:

Experiment	[RBr] (M)	[OH^-] (M)	Initial rate (M/s)
1	0.10	0.10	1.2×10^{-5}
2	0.10	0.30	2.8×10^{-5}
3	0.20	0.10	2.4×10^{-5}

(a) The rate law has the form rate = k1[RBr] + k2[RBr][OH^-]. Find k1 and k2 with units.

(b) Name the mechanism associated with each term.

(c) Predict the rate when [RBr] = 0.20 M and [OH^-] = 0.50 M, and the fraction of the reaction following the first term.

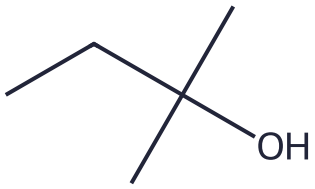
25 Challenge

Starting from 2-methylbutan-2-ol, outline a synthesis of each target using only reagents from this chapter:

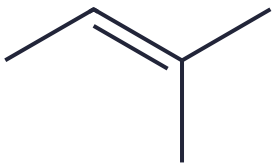
(a) 2-methylbut-2-ene;

(b) 2-methylbut-1-ene;

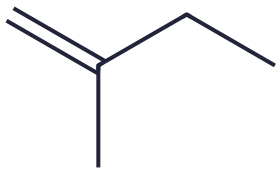
(c) 2-ethoxy-2-methylbutane.



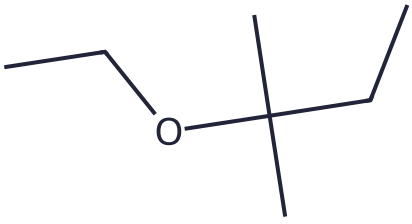
2-methylbutan-2-ol



(a) 2-methylbut-2-ene



(b) 2-methylbut-1-ene



(c) 2-ethoxy-2-methylbutane

For (c), explain why treating the corresponding tertiary bromide with sodium ethoxide would fail.

Part B Worked solutions

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

Easy One idea at a time

1 Easy

SN2, nucleophilicity

Answer $I^- > Br^- > Cl^- > F^-$

Solution

1. Methanol is polar protic, so every anion is surrounded by O-H hydrogen bonds from the solvent.
2. Small, charge-dense ions (F^-) are held tightly in that solvent shell; the shell must be partly stripped off before the ion can attack carbon.
3. Large ions (I^-) have charge spread over a bigger, more polarizable electron cloud; they are less tightly solvated and their electron cloud distorts easily toward the electrophilic carbon in the transition state.
4. So nucleophilicity increases down the group in protic solvents: $I^- > Br^- > Cl^- > F^-$.
5. Common mistake: ranking by basicity (F^- is the strongest base). Basicity and nucleophilicity track each other across a row, but in protic solvents they diverge going down a column.

2 Easy

LG, leaving-group ability

Answer $Br^- > Cl^- > H_2O > HO^- > NH_2^-$. A tosylate works because TsO- is the conjugate base of a strong acid (TsOH, pKa about −3) and its charge is delocalized over three oxygens and into the sulfonyl group and its aryl ring; it is a better leaving group than Cl^- or Br^-.

Solution

1. Good leaving groups are weak bases that are stable on their own; compare the pKa of the conjugate acids: HBr (about −9), HCl (about −7), H_3O^+ (about −1.7), H_2O (15.7), NH_3 (about 38).
2. The lower the pKa of the conjugate acid, the better the leaving group, which gives the order above.
3. Water leaves easily only because the oxygen has first been protonated; this is why strong acid is needed to convert R-OH to R-Br.
4. Tosylate: the negative charge is shared by three oxygens by resonance, so TsO- is a very weak base (like the best halides), and it is installed on the alcohol oxygen without breaking the C-O bond.
5. Common mistake: calling HO^- a leaving group in an SN2 or E2 step. HO^- is a poor leaving group; the OH must be activated (protonated or converted to OTs) first.

3 Easy

SN2, rate law, curved arrows

Answer (a) SN2; rate = k[RBr][N3-]. (b) 3 times faster. (c) unchanged (2 x 1/2 = 1). (d) one arrow from the lone pair on a terminal N of azide to the carbon bearing Br; one arrow from the C-Br bond to Br.

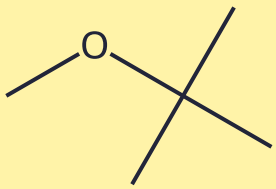
Solution

1. Primary alkyl halide, strong anionic nucleophile, polar aprotic solvent: classic SN2 conditions.
2. In SN2 the single step contains both reactants, so the rate is first order in each and second order overall: rate = k[RBr][N3-].
3. Tripling [N3-] triples the rate; doubling [RBr] and halving [N3-] gives a factor 2 x 0.5 = 1.
4. Arrow 1 starts at the lone pair on the nucleophile and ends on the electrophilic carbon (backside to Br); arrow 2 starts at the C-Br sigma bond and ends on Br, which leaves as bromide.
5. Common mistake: writing the rate law from the balanced equation by counting coefficients. Rate laws come from the mechanism (here it happens to match, but for SN1 it will not).

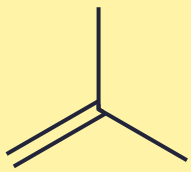
4 Easy

SN1, mechanism, energy diagram, carbocation stability

Answer (a) SN1; rate = k[t-BuBr]. (b) Two main steps (ionization, then nucleophile capture) show two transition states and one carbocation intermediate in a valley between them; the first (ionization) TS is highest. (c) Major: methyl tert-butyl ether; minor: 2-methylpropene. (d) tert-butyl > isopropyl > ethyl > methyl.



(c) methyl tert-butyl ether



2-methylpropene

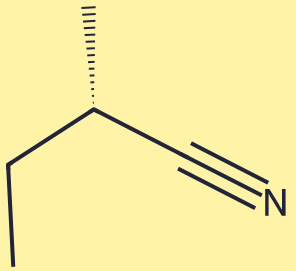
Solution

1. Tertiary halide plus a weak nucleophile in a polar protic solvent, no strong base: SN1 (and E1).
2. Step 1 is the slow ionization to give the cation and Br^-; step 2 is the fast capture by CH_3OH; step 3 is loss of H^+ from the oxonium ion (a fast proton transfer).
3. Only the substrate is in the slow step, so rate = k[t-BuBr]; adding more methanol (already the solvent) does not change the rate.
4. The cation is flanked by three alkyl groups that donate through hyperconjugation and induction, so stability falls as 3 degrees > 2 degrees > 1 degrees > methyl.
5. Common mistake: drawing the intermediate as a peak. A carbocation intermediate sits in a valley between the two transition states.

5 Easy

SN2, stereochemistry

Answer (S)-2-methylbutanenitrile.



–2-methylbutanenitrile

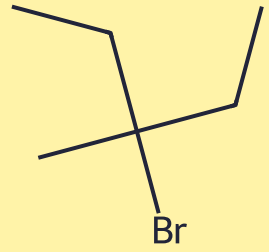
Solution

1. Secondary bromide, good nucleophile, polar aprotic solvent: SN2.
2. SN2 goes by backside attack, so the stereocenter undergoes inversion: the cyano group enters on the face opposite to bromine.
3. In the starting material the CIP priorities are Br > CH_2CH_3 > CH_3 > H. In the product the carbon of CN (N,N,N) outranks CH_2CH_3 (C,H,H), so the order is CN > CH_2CH_3 > CH_3 > H, the same pattern with CN in Br's place.
4. Inverted geometry plus an unchanged priority pattern means R becomes S.
5. Common mistake: believing SN2 always changes the label R to S. Inversion of geometry is certain; the letter changes only if the priority order of the groups stays the same, so always re-assign the CIP priorities.

6 Easy

ROH, alcohol + HBr

Answer (a) 3-Bromo-3-methylpentane by SN1. (b) 1-Bromobutane by SN2.



(a) 3-bromo-3-methylpentane



(b) 1-bromobutane

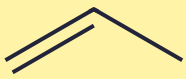
Solution

1. In both cases the acid protonates the OH to make a water leaving group (an oxonium ion).
2. (a) The tertiary oxonium ion loses water to give a tertiary carbocation; bromide then captures it. No rearrangement is needed since the cation is already tertiary.
3. (b) A primary cation is far too unstable, so bromide attacks the protonated primary alcohol in a concerted backside displacement of water (SN2).
4. Rate laws: (a) rate depends on the protonated alcohol only; (b) first order in each, protonated alcohol and Br^-.
5. Common mistake: using Br^- directly on the neutral alcohol. HO^- cannot leave; protonation (or tosylation) must come first.

7 Easy

Williamson ether synthesis

Answer Route 1. The reaction is SN2; Route 2 mainly gives propene by E2.



propene

Solution

1. The Williamson synthesis is an SN2 attack by an alkoxide on an alkyl halide, so the halide should be methyl or primary.
2. Route 1 attacks a primary carbon (bromoethane): good for SN2.
3. Route 2 attacks a secondary carbon with a strong, unhindered base/nucleophile; E2 competes and wins, so propene is the main product.
4. The alkoxide can be made by deprotonating the alcohol with NaH (or Na metal).
5. Common mistake: choosing the pair based on which fragment seems "bigger". Always put the more substituted carbon on the oxygen (alkoxide) and the less substituted carbon on the halide.

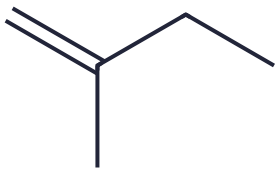
8 Easy

E2, alkene stability, Zaitsev

Answer (a) 2-methylbut-2-ene > (E)-pent-2-ene > (Z)-pent-2-ene > pent-1-ene. (b) 2-Methylbut-2-ene (Zaitsev product).

Solution

1. Alkyl groups stabilize a C=C by hyperconjugation: more substituted is more stable. 2-Methylbut-2-ene is trisubstituted, pent-2-ene isomers are disubstituted, pent-1-ene is monosubstituted.
2. Within the disubstituted pair, the E isomer avoids the steric clash of the two alkyl groups on the same side that the Z isomer has.
3. Ethoxide is a strong, small base, so E2 gives mainly the more stable (more substituted) alkene: Zaitsev's rule.
4. The minor product is 2-methylbut-1-ene.



2-methylbut-1-ene

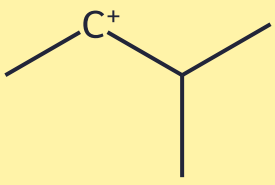
5. Common mistake: concluding the lowest-energy alkene must be the major product in every E2. That holds for small bases; bulky bases (see Q14) change it.

Exam *Test-level, multi-step*

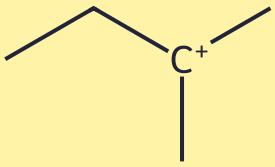
9 Exam

SN1, hydride shift, rearrangement

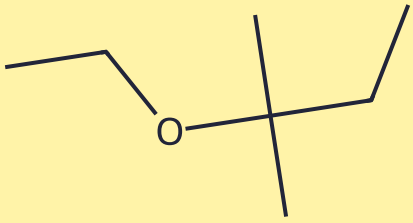
Answer (a) SN1/E1; rate = k[RBr]. (b) secondary cation → 1,2-hydride shift → tertiary cation. (c) Substitution: 2-ethoxy-2-methylbutane; elimination: 2-methylbut-2-ene.



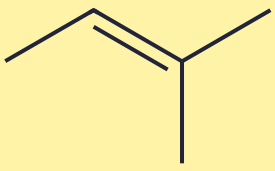
(b) secondary cation



tertiary cation



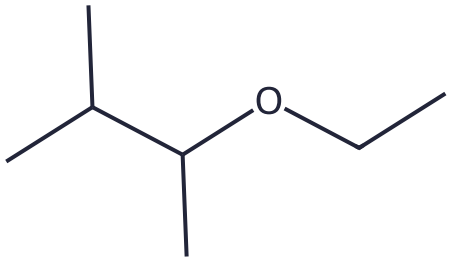
(c) 2-ethoxy-2-methylbutane



2-methylbut-2-ene

Solution

1. Secondary halide, weak nucleophile/base (ethanol), polar protic solvent, heat: unimolecular chemistry through a carbocation.
2. Ionization gives a secondary cation at C2, next to C3 which carries a hydrogen and is bonded to two methyl groups and C2.
3. A hydride on C3 moves with its electron pair to C2 (a 1,2-hydride shift): the positive charge moves to C3, which is tertiary and more stable.
4. Ethanol attacks the tertiary cation and the oxonium ion is deprotonated: 2-ethoxy-2-methylbutane. Loss of a proton from a neighboring carbon gives the Zaitsev alkene 2-methylbut-2-ene.
5. Common mistake: drawing the "direct" product 2-ethoxy-3-methylbutane without checking whether the cation can rearrange to something more stable.

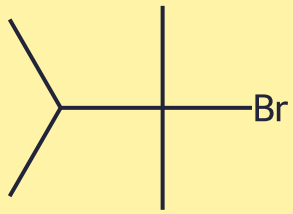


2-ethoxy-3-methylbutane

10 Exam

ROH, HBr, methyl shift

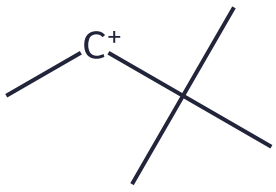
Answer 2-Bromo-2,3-dimethylbutane.



2-bromo-2,3-dimethylbutane

Solution

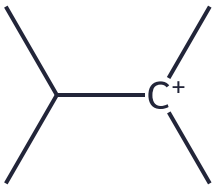
1. Protonate the OH; loss of water gives the secondary cation.



secondary cation

2. The adjacent carbon is quaternary (no H), so a hydride shift is impossible, but a methyl group with its bonding pair can migrate (1,2-methyl shift) to the cationic carbon.

3. After the shift, the former quaternary carbon (C3) holds the positive charge with two methyls and C2 attached, while C2 is now $CH(CH_3)_2$: the cation is a tertiary cation (2,3-dimethylbutan-2-yl cation).



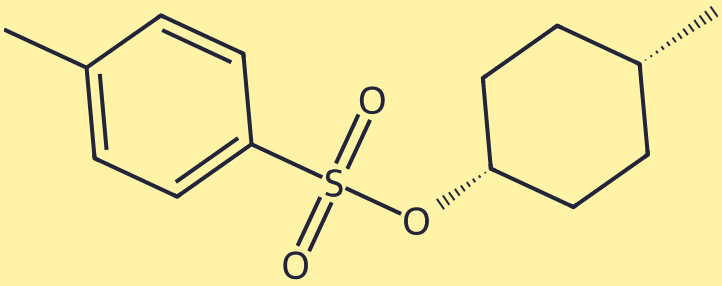
tertiary cation

4. Bromide captures the tertiary cation to give 2-bromo-2,3-dimethylbutane.
5. This is why the unrearranged bromide is not the major product: the secondary cation rearranges to the tertiary cation before bromide can capture it.
6. Common mistake: assuming "no rearrangement" for an alcohol that gives a secondary cation next to a quaternary carbon. A secondary cation next to a quaternary carbon is a signal to check for a methyl shift.

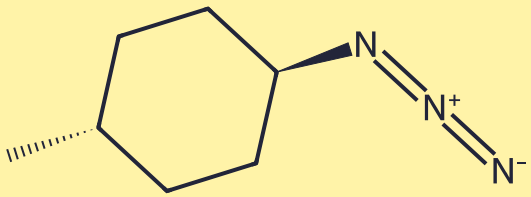
11 Exam

ROH, tosylate, SN2, retention then inversion

Answer Intermediate: cis-4-methylcyclohexyl tosylate (retention). Final: trans-1-azido-4-methylcyclohexane (inversion).



cis-4-methylcyclohexyl tosylate



trans-1-azido-4-methylcyclohexane

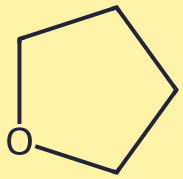
Solution

1. Step 1: the alcohol oxygen attacks sulfur of TsCl; pyridine removes the proton. The C-O bond is never broken, so the carbon keeps its configuration (retention). The OTs group is cis to the methyl.
2. Step 2: azide is a good nucleophile and weak base, DMSO is polar aprotic, so SN2 occurs with backside attack and inversion.
3. The azide ends up on the opposite face from where the OTs was, so it is trans to the methyl group.
4. Net result: ROH to RN_3 with inversion, two steps. (Some E2 competes with a secondary tosylate, but azide is weakly basic so substitution dominates.)
5. Common mistake: counting two inversions (tosylation plus substitution). Only the SN2 step inverts.

12 Exam

Williamson, intramolecular

Answer (a) Tetrahydrofuran by intramolecular SN2; hydrogen gas. (b) The reacting ends are held in the same molecule, giving a high effective concentration and a favorable 5-membered ring TS.



(a) tetrahydrofuran

Solution

1. NaH is a strong base, not a nucleophile; it removes the OH proton to give the alkoxide and H_2 gas.



alkoxide

2. The alkoxide oxygen can reach the carbon bearing Br by a 5-membered cyclic transition state (O, C1, C2, C3 and C4 form a 5-membered ring in the transition state).
3. Backside attack at the primary carbon displaces bromide: a Williamson ether synthesis in one molecule gives the ring.
4. Five- and six-membered rings form fastest because strain and entropy cost are small; two reactive ends in one molecule collide far more often than two separate molecules do.
5. Common mistake: expecting E2 because a "strong base" is used. The substrate is a primary bromide, and the alkoxide is tied to the same molecule.

13 Exam

Solvent effects

Answer (a) DMSO. (b) 1:1 ethanol/water. (c) In DMSO: $Cl^- > Br^- > I^-$ (the reverse of the methanol order $I^- > Br^- > Cl^-$).

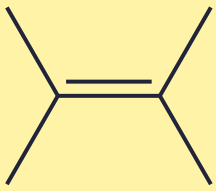
Solution

1. (a) SN2 with an anionic nucleophile. Polar aprotic DMSO solvates the Na^+ but leaves the CN^- anion poorly solvated ("naked"), so it is far more reactive than in methanol where hydrogen bonds blunt it.
2. (b) SN1: the slow step makes ions. A more polar, more strongly hydrogen-bonding mixture (higher water content) stabilizes the developing cation and the leaving halide in the transition state, so ionization is faster.
3. (c) Without a hydrogen-bonding shell, intrinsic reactivity follows charge density and basicity: smaller, more basic anions are better nucleophiles, so the order reverses to $Cl^- > Br^- > I^-$ (this assumes free, non-ion-paired anions, for example Bu4N+ salts; with Na^+ salts ion pairing can compress the differences).
4. This reversal is the key test of whether you understand that "nucleophilicity" depends on the solvent.
5. Common mistake: memorizing "I^- is the best nucleophile" as a solvent-independent fact.

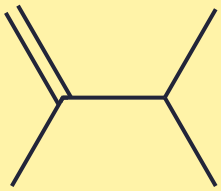
14 Exam

E2, Zaitsev vs Hofmann, base size

Answer (i) 2,3-Dimethylbut-2-ene (Zaitsev, tetrasubstituted). (ii) 2,3-Dimethylbut-1-ene (Hofmann, 1,1-disubstituted).



(i) 2,3-dimethylbut-2-ene



(ii) 2,3-dimethylbut-1-ene

Solution

1. The halide is tertiary, so SN2 is impossible; with a strong base the pathway is E2 in both cases.
2. Beta hydrogens: six on the two equivalent CH_3 groups (give the Hofmann product) and one on the $CH(CH_3)_2$ carbon (gives the tetrasubstituted alkene).
3. Ethoxide is small and reaches the single tertiary C-H; the transition state resembles the most stable alkene, so Zaitsev wins.
4. tert-Butoxide is bulky: reaching a crowded tertiary C-H is hard, but the six unhindered methyl hydrogens are easy to remove, giving the less substituted alkene.
5. Common mistake: believing a bulky base always stops elimination from happening. It does not change E2 vs SN2 here; it changes only which proton it takes.

15 Exam

SN2, substrate effects, steric hindrance

Answer CH_3Br > CH_3CH_2Br > $(CH_3)_2CHBr$ > $(CH_3)_3CCH2Br$. tert-Butyl bromide does not undergo SN2.

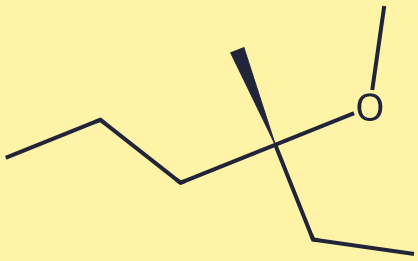
Solution

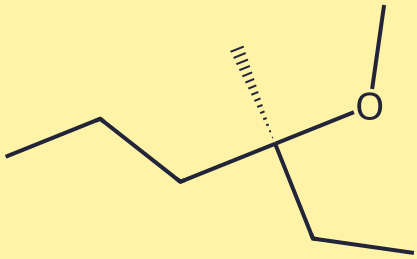
1. SN2 needs backside access to the carbon; each additional alkyl group on the carbon, or on the neighboring carbon, adds steric hindrance in the crowded transition state.
2. Methyl is the least hindered, then ethyl (primary), then isopropyl (secondary, two alkyl groups on the reacting carbon).
3. Neopentyl is primary, but its adjacent tert-butyl group (a quaternary beta carbon) blocks the backside approach, making it much slower than even secondary halides.
4. tert-Butyl bromide has three alkyl groups on the reacting carbon: SN2 is not observed in practice.
5. Common mistake: ranking by "primary, secondary, tertiary" labels alone. Branching at the beta carbon matters as well.

16 Exam

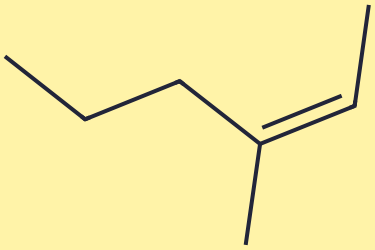
SN1, stereochemistry of chiral tertiary halide

Answer (a) SN1; 3-methoxy-3-methylhexane as the racemic pair and. (b) No (racemic, optically inactive). (c) 3-Methylhex-2-ene and 3-methylhex-3-ene, or 2-ethylpent-1-ene.

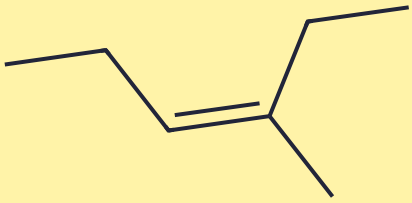




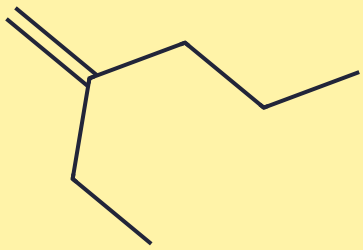
(a) racemic pair



(c) 3-methylhex-2-ene



3-methylhex-3-ene



2-ethylpent-1-ene

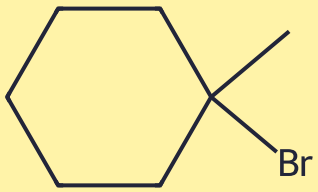
Solution

1. A tertiary halide in a protic, weakly nucleophilic solvent ionizes to a carbocation; the carbocation carbon is sp^2 and planar, with three different groups (methyl, ethyl, propyl), so it has no stereochemical memory.
2. Methanol can attack either face with equal probability, giving equal amounts of R and S ethers.
3. A 1:1 mixture of enantiomers is optically inactive (racemic). In real life a slight excess of inversion can occur because of ion-pair effects, but the exam answer is racemization.
4. Alkenes by E1: loss of H^+ from the CH_2 of the ethyl group gives 3-methylhex-2-ene, from the CH_2 of the propyl group gives 3-methylhex-3-ene (both more substituted, favored), and from the CH_3 gives the less substituted 2-ethylpent-1-ene.
5. Common mistake: assigning inversion only (that is SN2) or complete retention.

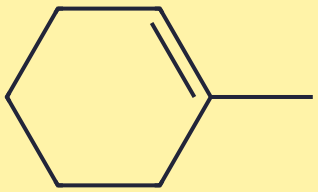
17 Exam

ROH, HBr vs H_2SO_4 (substitution vs elimination of alcohols)

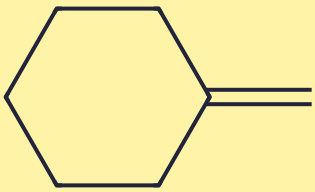
Answer (i) 1-Bromo-1-methylcyclohexane (SN1). (ii) 1-Methylcyclohexene (E1, Zaitsev); minor: methylenecyclohexane.



(i) 1-bromo-1-methylcyclohexane



(ii) 1-methylcyclohexene



methylenecyclohexane

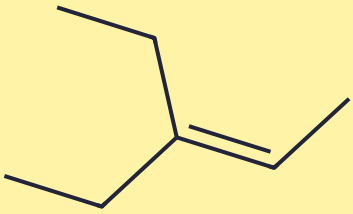
Solution

1. Both reagents protonate the tertiary OH; water leaves to give the 1-methylcyclohexyl cation.
2. With HBr, bromide is a good nucleophile in high concentration and low temperature favors capture of the cation: alkyl bromide.
3. With H_2SO_4, HSO_4^- is a very poor nucleophile and a weak base that removes a proton from a neighboring carbon; heat favors the entropy-increasing elimination, and the alkene can be distilled away.
4. Removing a ring hydrogen gives the trisubstituted 1-methylcyclohexene (more stable) rather than the disubstituted exocyclic alkene.
5. Common mistake: using the same mechanism label for both without explaining that the counterion (Br^- vs HSO_4^-) and the temperature decide between SN1 and E1.

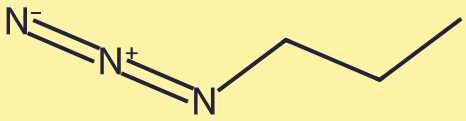
Answer (a) SN2: 1-methoxybutane. (b) E2: 3-ethylpent-2-ene. (c) SN2: 1-azidopropane. (d) SN1 (with E1): methyl tert-butyl ether major, 2-methylpropene minor. (e) E2: propene major, with isopropyl ethyl ether as the minor SN2 product.



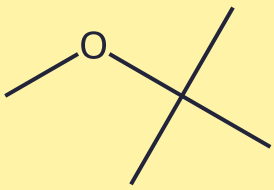
(a) 1-methoxybutane



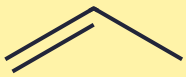
(b) 3-ethylpent-2-ene



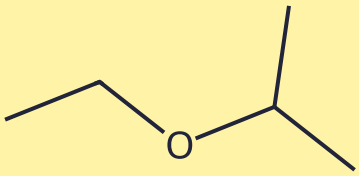
(c) 1-azidopropane



(d) methyl tert-butyl ether



(e) propene



isopropyl ethyl ether

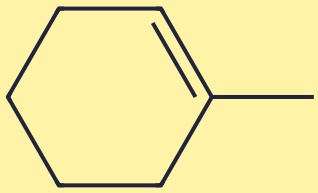
Solution

1. First decide the function of the reagent: strong base and nucleophile (alkoxide), good nucleophile and weak base (azide), or weak nucleophile and weak base (solvent).
2. (a) Primary substrate with a small strong nucleophile: SN2 beats E2.
3. (b) Tertiary substrate with strong base: E2 (SN2 impossible). Only one alkene is possible because the substrate is symmetric.
4. (c) Primary with azide in a polar aprotic solvent: SN2. (d) Tertiary, weak nucleophile, protic solvent, no base: SN1 and E1 through the cation; substitution dominates at room temperature.
5. (e) Secondary substrate with a strong base and heat: E2 major. Common mistake: choosing SN2 for any "alkoxide plus halide" pair without checking the substrate class and temperature.

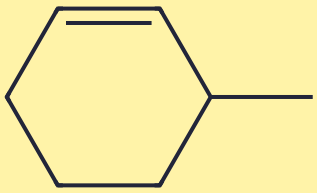
19 Challenge

Stereo, E2 in cyclohexanes (chair)

Answer (a) cis → 1-methylcyclohexene; trans → 3-methylcyclohexene (racemic). (b) The cis isomer is faster.



(a) 1-methylcyclohexene



3-methylcyclohexene

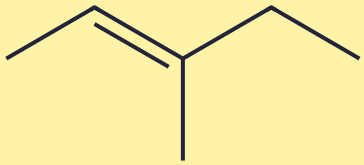
Solution

1. E2 requires the H and the Br to be anti-periplanar; in a chair that means both axial (trans-diaxial). The Br must be axial.
2. cis isomer: one substituent is axial, the other equatorial. In the chair with Br axial the methyl is equatorial, so the hydrogen on C2 is axial and anti to Br. Removing it forms the C1=C2 double bond; C2 carries the methyl, so the product is the trisubstituted 1-methylcyclohexene.
3. trans isomer: the chair with axial Br puts the methyl axial too (trans-diaxial). The C2 hydrogen is then equatorial and cannot be anti to Br, so elimination toward C2 is geometrically impossible. The axial H on C6 is anti to Br, giving the less substituted 3-methylcyclohexene.
4. The reactive chair of the trans isomer has two axial groups (about 2 kcal/mol less stable), so fewer molecules are in the reactive conformation and the reaction is slower. The cis isomer reacts in its more stable chair (Br axial costs less than methyl axial).
5. Common mistake: applying Zaitsev's rule automatically. The anti-periplanar requirement can override it, and ring-flip must be considered.

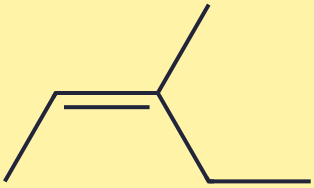
20 Challenge

Stereo, E2 stereospecificity (Newman projection)

Answer (2R,3R) gives (E)-3-methylpent-2-ene. (2S,3R) gives (Z)-3-methylpent-2-ene.



(E)-3-methylpent-2-ene



(Z)-3-methylpent-2-ene

Solution

1. The reactive conformer has the C3-H anti to the C2-Br.
2. (2R,3R), viewing from C2 (front) to C3 (back), Br at 12 o'clock: front CH_3 at 4 o'clock and H at 8 o'clock. Back carbon: H at 6 o'clock (anti to Br), CH_3 at 2 o'clock and CH_2CH_3 at 10 o'clock.
3. After loss of H and Br, the groups on each carbon fold into the plane. Front CH_3 (4 o'clock) and back CH_2CH_3 (10 o'clock) are on opposite sides (180 degrees apart), so they end up trans: (E).
4. (2S,3R): front CH_3 at 8 o'clock, H at 4 o'clock; back unchanged (H 6, CH_3 2, Et 10). Now front CH_3 (8) and back ethyl (10) are gauche and end up cis: (Z).
5. At the double bond, the higher-priority groups are CH_3 on C2 (vs H) and CH_2CH_3 on C3 (vs CH_3), so trans is E, cis is Z.
6. The two diastereomers give different alkene geometries: E2 is stereospecific. Common mistake: assuming E2 gives the E (trans) alkene from either diastereomer because trans is more stable. (The C1 methyl hydrogens can also be removed, giving a little 3-methylpent-1-ene, but the question asks about the major, more substituted alkene.)

21 Challenge

Williamson (intramolecular), Stereo (anti requirement)

Answer (a) The trans isomer. (b) In the cis isomer the OH and Br can never both be axial, so the alkoxide cannot reach the backside of the C-Br bond. The epoxide-forming step is an intramolecular SN2 (an intramolecular Williamson reaction).

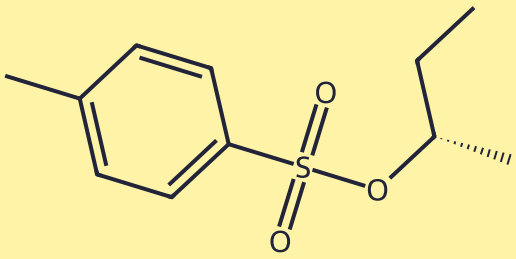
Solution

1. NaOH deprotonates the OH (pKa about 16) to give an alkoxide in equilibrium; the alkoxide is the nucleophile.
2. For the alkoxide oxygen to attack the carbon bearing Br from the back side, O, C1, C2 and Br must be in a line across the ring bond: O and Br must be anti, i.e. both axial (trans-diaxial) on a chair.
3. In the trans isomer, the ring flip to the diaxial chair puts the O^- and Br axial and anti, so the SN2 closes the three-membered ring, with inversion at C-Br.
4. In the cis isomer, one group is axial and the other equatorial in either chair; the O^- is roughly 60 degrees from the Br and cannot reach the backside. No epoxide forms by this path; slow elimination or substitution products form instead (for example, removing the C1 hydrogen anti to the axial Br gives an enol that ends up as cyclohexanone, or removing the axial C3 hydrogen gives 2-cyclohexen-1-ol).
5. Common mistake: assuming both isomers cyclize because they have the same functional groups. Stereochemistry decides.

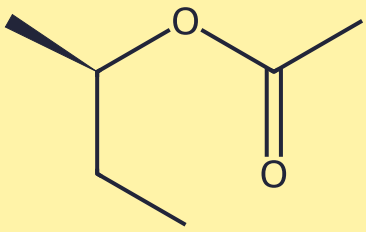
22 Challenge

ROH, tosylate, SN2, inversion strategy

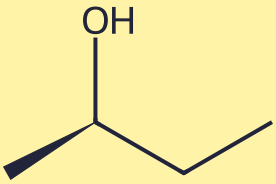
Answer (1) TsCl, pyridine → (S)-butan-2-yl tosylate (retention). (2) Sodium acetate in DMSO → (R)-butan-2-yl acetate (SN2, inversion). (3) NaOH, H_2O (then acid workup) → (R)-butan-2-ol.



(S)-butan-2-yl tosylate



(R)-butan-2-yl acetate

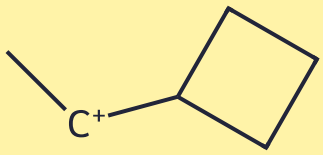


(R)-butan-2-ol

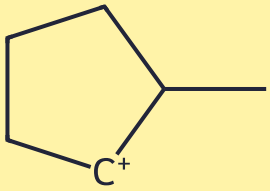
Solution

1. Step 1: O-S bond formation; the stereocenter's C-O bond is untouched, so the configuration (S) is kept.
2. Step 2: acetate is a decent nucleophile but only a weak base (conjugate acid pKa 4.8), so SN2 on a secondary tosylate beats E2. A polar aprotic solvent keeps it reactive. Backside attack inverts the stereocenter: S to R (the priority pattern O > Et > Me > H is unchanged).
3. Step 3: hydroxide attacks the ester carbonyl carbon (addition-elimination), and the C-O bond to the stereocenter is not broken, so configuration is retained: (R)-butan-2-ol.
4. HBr on a secondary alcohol gives partial SN1 character (racemization and possible shifts), and NaOH on a secondary tosylate gives mainly E2 (butenes) because HO^- is a strong base.
5. Common mistake: using hydroxide directly to open the tosylate, or counting step 3 as another inversion. Only the SN2 step inverts.

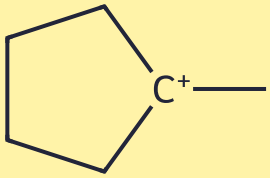
Answer Protonation, loss of water to give the secondary cation; ring expansion (C-C bond migration) to the secondary 2-methylcyclopentyl cation, then a 1,2-hydride shift to the tertiary 1-methylcyclopentyl cation; bromide capture gives.



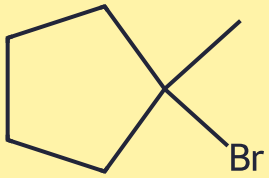
secondary cation



secondary 2-methylcyclopentyl cation

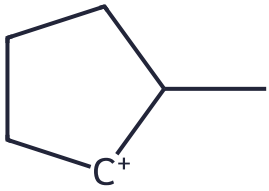


tertiary 1-methylcyclopentyl cation



Solution

1. Protonation of the OH and loss of water gives the secondary cation next to the cyclobutane ring.
2. A ring carbon-carbon bond adjacent to the cationic carbon migrates (like an alkyl shift): one ring bond moves to the cationic carbon, enlarging the ring from four to five members. The new cation is a secondary cation at the former ring attachment point, (the methyl-bearing carbon is next to the cationic carbon).



3. The relief of ring strain (about 26 kcal/mol for cyclobutane vs about 6 for cyclopentane) drives this shift even though the cation is only secondary before and after it.
4. The methyl-bearing carbon next to the cationic center has one hydrogen; a 1,2-hydride shift moves the charge there, forming the tertiary 1-methylcyclopentyl cation, which is the most stable cation in the sequence.
5. A competing 1,2-hydride shift from the ring would give the tertiary 1-methylcyclobutyl cation, but the ring-expanded 1-methylcyclopentyl cation is the strain-free, thermodynamically favored one, so this is the cation we follow. (This is a textbook-style prediction of the major product.)
6. Bromide captures the tertiary cation. Common mistake: stopping after the ring expansion, or writing a primary carbocation on the ring. Always follow the cation to the most stable position and check ring strain.

24 Challenge

Competing, kinetics and rate law (quantitative)

Answer (a) k1 = 4.0 x 10^{-5} s^{-1}; k2 = 8.0 x 10^{-4} M^{-1} s^{-1}. (b) k1: unimolecular (SN1/E1); k2: bimolecular (SN2/E2). (c) 8.8 x 10^{-5} M/s; about 9%.

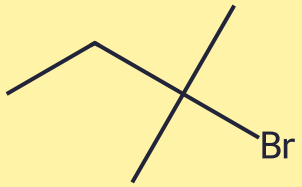
Solution

1. Divide each rate by [RBr] to get the effective first-order constant: Exp 1: 1.2 x 10^{-4} s^{-1}; Exp 2: 2.8 x 10^{-4} s^{-1}; Exp 3: 1.2 x 10^{-4} s^{-1} (the same as Exp 1, confirming first order in RBr).
2. These equal k1 + k2[OH^-]. Subtract Exp 1 from Exp 2: k2(0.30 - 0.10) = 1.6 x 10^{-4}, so k2 = 8.0 x 10^{-4} M^{-1} s^{-1}.
3. Then k1 = 1.2 x 10^{-4} - (8.0 x 10^{-4})(0.10) = 4.0 x 10^{-5} s^{-1}.
4. The term with no [OH^-] is the ionization (SN1/E1) route; the term proportional to [OH^-] is the bimolecular route (SN2/E2).
5. Prediction: rate = 0.20 x (4.0 x 10^{-5} + 8.0 x 10^{-4} x 0.50) = 0.20 x 4.4 x 10^{-4} = 8.8 x 10^{-5} M/s. Fraction unimolecular = 4.0 x 10^{-5} / 4.4 x 10^{-4} = 0.091, about 9%.
6. Common mistake: assuming a single mechanism for a secondary substrate. Secondary halides can show both pathways at once, and changing [base] shifts the balance.

25 Challenge

Roadmap, competing pathways, Williamson, E1/E2

Answer (a) conc. H_2SO_4, heat (E1, Zaitsev). (b) HBr (0 degrees C) to give 2-bromo-2-methylbutane, then potassium tert-butoxide in tert-butanol, heat (E2, Hofmann). (c) NaH to give the tertiary alkoxide, then bromoethane or iodoethane (Williamson, SN2 at a primary carbon).



(b) 2-bromo-2-methylbutane

Solution

1. (a) Acid-catalyzed dehydration goes through the tertiary cation and loses H^+ to give the most stable alkene (trisubstituted).
2. (b) The less substituted alkene needs a bulky base, which needs a halide, not an alcohol. Make the tertiary bromide first (SN1 with HBr), then use KOtBu to remove the less hindered CH_3 hydrogen (Hofmann).
3. (c) The ether has a tertiary carbon on oxygen and a primary ethyl group; the only workable Williamson disconnection puts the tertiary carbon on the alkoxide and the ethyl on the halide: tertiary alkoxide + CH_3CH_2-I, SN2 at the unhindered primary carbon.
4. The reverse approach (tertiary bromide + ethoxide) gives E2 alkenes, because SN2 at a tertiary carbon is impossible and ethoxide is a strong base.
5. Dissolving the tertiary bromide in ethanol without base gives some ether by SN1, but also E1 alkenes, so it is not clean.
6. Common mistake: choosing the SN1 route in (c), or using a strong small base in (b), which would simply give the Zaitsev alkene again.