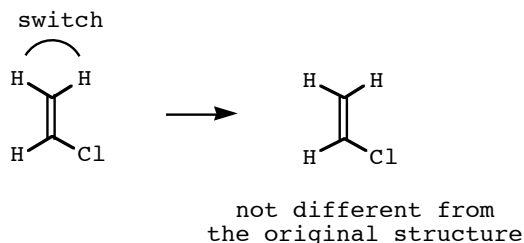


The *E,Z* system**“cis” and “trans” stereochemical descriptors in use with alkenes**

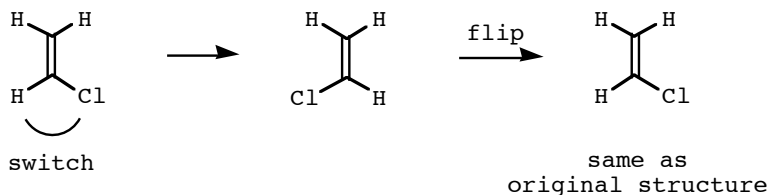
We saw in a previous lecture that the stereochemical descriptors “*cis*” and “*trans*” are employed to describe the relative stereochemistry of two substituents on a ring. These terms are also used to indicate stereochemical relationship in alkenes. The correct use of these terms is rather tricky. The alkene must satisfy two requirements:

- (1) The carbon–carbon double bond must be stereogenic.
- (2) Both alkene carbons must have an equivalent substituent.

A double bond is stereogenic if switching the groups at one alkene carbon results in a structure different from the original. For example, switching the C2 hydrogens in 1-chloro-1-ethene does not result in a new structure so the double bond is not stereogenic:

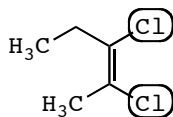


Switching the groups at C1 groups doesn't result in a new structure either: it's merely the original structure flipped like a pancake:



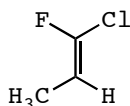
The second requirement that must be fulfilled before “*cis*” or “*trans*” can be used is that both alkene carbons must have an equivalent substituent, that is, both alkene carbons must be bonded to hydrogen atoms, or to chlorine atoms, or to methyl groups, etc.

The "cis" or "trans" labels are appropriate to the 2,3-dichloro-2-pentene structure shown below. Switching the groups at one of the alkene carbon results in a new structure (i.e., the double bonds are stereogenic) and both alkene carbons are bonded to equivalent substituents, namely, to two chlorines.



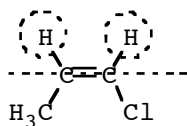
"cis" or "trans" OK

In contrast, the "cis" and "trans" labels are not appropriate to the 1-chloro-1-fluoro-1-propene structure shown below because the alkene carbons do not bear an equivalent substituent: the substituents at C1 are completely different from those at C2.

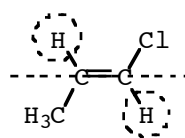


"cis" or "trans" not OK

To determine whether a stereogenic carbon-carbon double bond is *cis* or *trans*, draw an imaginary line collinear with that carbon-carbon double bond. The structure that has the equivalent substituents on the same side of the imaginary line is the *cis* stereoisomer; the structure that has the equivalent substituents on opposite sides of the imaginary line is the *trans* stereoisomer. We will demonstrate with the two 1-chloro-1-propene structures below:



*cis*-1-chloro-1-propene



*trans*-1-chloro-1-propene

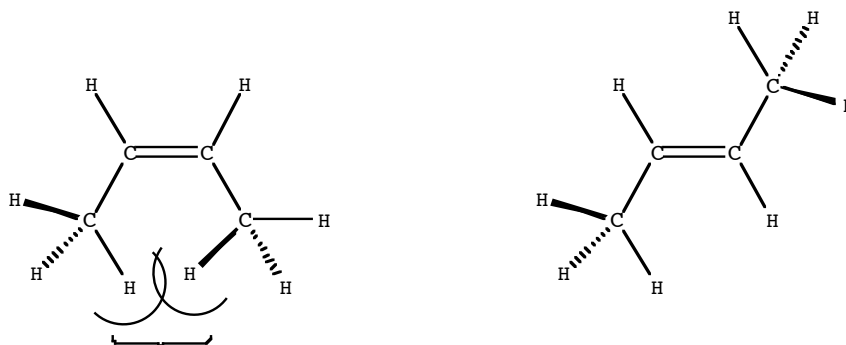
Problem How are *cis*- and *trans*-1-chloro-1-propene stereochemically related?

Answer They are diastereomers.

Problem The standard enthalpy of formation  $\Delta H^\circ_f$  of *trans*-2-butene is equal to  $-11.17$  kJ/mol, whereas the  $\Delta H^\circ_f$  of *cis*-2-butene is equal to  $-6.99$  kJ/mol.

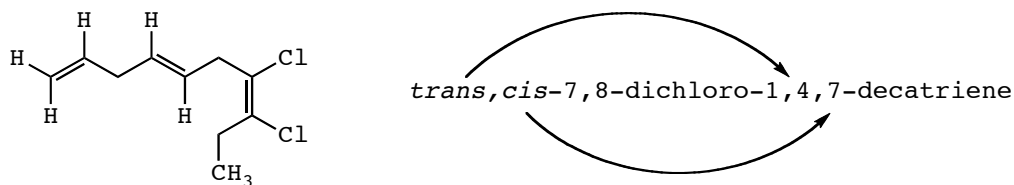
Which diastereomer is more stable? Explain why the stability of the two compounds differs.

Answer *trans*-2-Butene is more stable. The methyl groups are close together in *cis*-2-butene: the electrons surrounding the methyl groups interact repulsively and destabilize the molecule. The methyl groups are far apart in *trans*-2-butene. This is an example of steric strain caused by non-bonded-electron repulsion:



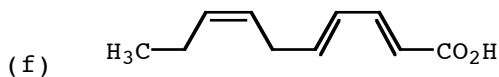
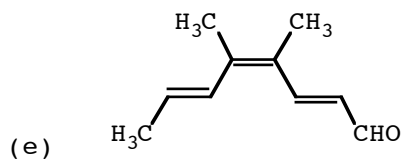
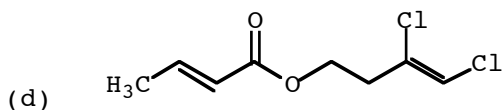
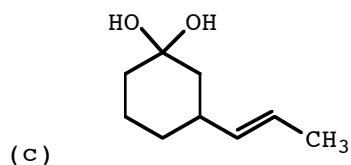
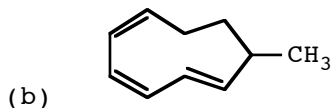
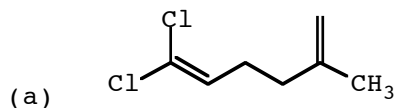
destabilizing non-bonded-electron  
repulsion absent in the  
*trans* stereoisomer

If a molecule has more than one alkene that can be labeled "*cis*" or "*trans*", those stereochemical descriptors are written in an order that parallels the position numbers of the carbon-carbon double bonds to which they refer. For example,



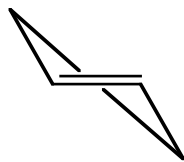
Note that in the example just given there are three double bonds but only two stereochemical descriptors. The first stereochemical descriptor in the name does not refer to the alkene at C1 because that alkene is not stereogenic and, as such, is not entitled to a stereochemical descriptor.

Problem Write the systematic name of these compounds; include the stereochemical descriptors "*cis*" and "*trans*" where appropriate.



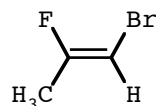
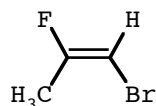
Answer (a) 1,1-dichloro-5-methyl-1,5-hexadiene (b) *cis,cis,trans*-7-methyl-1,3,5-cyclononatriene (c) 3-(*trans*-1-propenyl)-1,1-cyclohexanediol (d) *cis*-3,4-dichloro-3-butenyl *trans*-2-buten-1-oate (e) *trans,cis,trans*-4,5-dimethyl-2,4,6-octatrien-1-al (f) *trans,trans,cis*-2,4,7-decatrien-1-oic acid

A final word about "*cis*" or "*trans*": these stereochemical descriptors are normally not used in naming rings consisting of seven or fewer carbons because the double bonds in such rings can exist only in the *cis* form. What would *trans*-1-cyclopropene look like? Hmm. *trans*-1-Cyclobutene (shown below) does not exist either: its C3–C4 bond would have to be impossibly long and weak.



### **"E" and "Z" stereochemical descriptors used with alkenes**

We saw that the labels "*cis*" or "*trans*" can be attached to some alkenes, but we were careful to point out that these labels apply to alkenes only when (1) the double bond is stereogenic and (2) the two alkene carbons have an equivalent substituent. The second requirement disqualifies the two 1-bromo-2-fluoro-1-propene diastereomers below:



To distinguish such structures we follow a procedure developed by Robert Cahn, Christopher Ingold and Vladimir Prelog called the CIP *E,Z* system. We now present step-by-step rules for implementing the CIP *E,Z* system to simple cases. We then consider some more complicated situations.

**Step # 1**

Locate a stereogenic carbon-carbon double bond.

**Step # 2**

Draw an imaginary line perpendicular to the double bond.

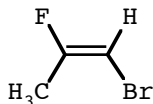
**Step # 3**

Rank the atoms directly bonded to the alkene carbon on one side of the imaginary line by atomic number high-to-low, then do likewise to the atoms directly bonded to the other alkene carbon on the other side of the imaginary line.

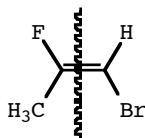
**Step # 4**

Connect the two higher-ranking groups on either side of the imaginary line. If you cross the carbon-carbon double bond to connect the two winning groups, the alkene has the *E* stereochemistry; if you don't cross the carbon-carbon double bond to connect the two winning groups, the alkene has the *Z* stereochemistry. The symbol "*E*" stands for the German word *entgegen* meaning "across", whereas the symbol "*Z*" is derived from the German word *zusammen* meaning "together".

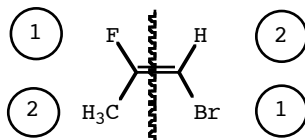
Problem Determine the stereochemistry (*E* or *Z*) of the molecule below:



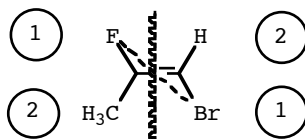
Answer First we assure ourselves that the carbon-carbon double bond is indeed stereogenic. We draw an imaginary line perpendicular to the carbon-carbon double bond:



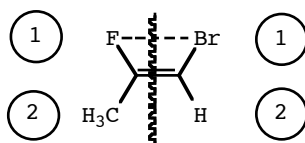
Now rank the atoms directly bonded to the alkene carbons on each side of the imaginary line by atomic number high-to-low:



Note that you are not ranking all four groups against each other: you are first ranking the groups on one side of the imaginary line and then the groups on the other side. Finally, connect the winning groups:

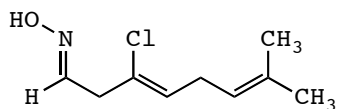


In this case, we cross the double bond to connect the higher ranking groups. Thus, the alkene has the *E* stereochemistry and the systematic name of the molecule is (1*E*)-1-bromo-2-fluoro-1-propene where the "1" in "1*E*" refers to the location of the carbon-carbon double bond. The structure below is (1*Z*)-1-bromo-2-fluoro-1-propene:

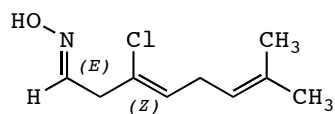


Whereas the labels "*cis*" and "*trans*" are not always appropriate, the labels "*E*" or "*Z*" can be applied to any stereogenic double bond, including carbon-nitrogen and carbon-oxygen double bonds.

Problem Determine the stereochemistry (*E* or *Z*) of the double bonds in this molecule:

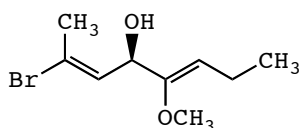


Answer



The substituents bonded to the N atom are OH and an electron pair; the OH wins. The carbon-carbon double bond on the far right is not stereogenic, so it doesn't get an "E" or a "Z".

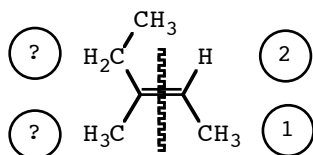
Problem Write the systematic name of this molecule.



Answer (2E,4R,5Z)-2-bromo-5-methoxy-2,5-octadien-4-ol. This example illustrates how to handle naming molecules that have more than one stereogenic alkene as well as a chirality center. We prefer the style that associates a position number with each stereochemical designation because that style requires no disambiguation. Sometimes and especially in the professional literature that would come to the attention only of nomenclature savants, the position numbers are dropped: you might see something like (E,R,Z)-2-bromo-5-methoxy-2,5-octadien-4-ol. Not recommended.

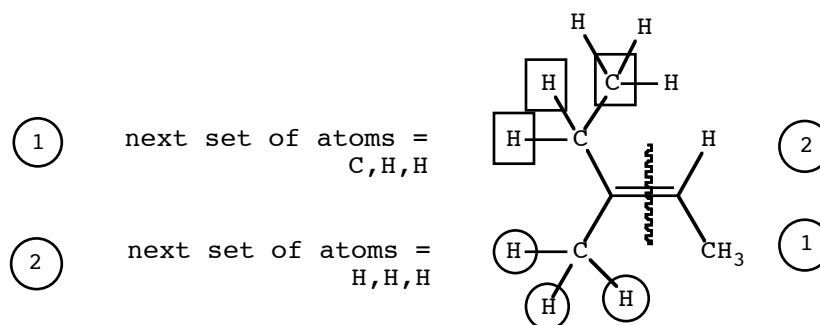
**More complex examples of the CIP E,Z system**

What would be the stereochemical designation (E or Z) of *cis*-3-methyl-2-pentene?



When we apply the CIP E,Z system rules to this compound, we immediately run into a problem: the atoms directly bonded to C3 are both carbons so no decision can be made concerning their rank by atomic number. In this situation, we must consider the next set of atoms, which is defined as all the atoms bonded to the previous set of atoms. The winner is the set that has the higher atomic-number atom at the first point of difference.

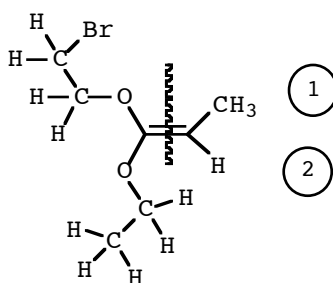
The methyl carbon bonded to C3 is bonded to three hydrogens, whereas the C4 carbon is bonded to the C5 carbon and two hydrogens. Writing each set of atoms in order of atomic number high-to-low gives {C,H,H} for the C4 carbon *versus* {H,H,H} for the methyl carbon bonded to C3:



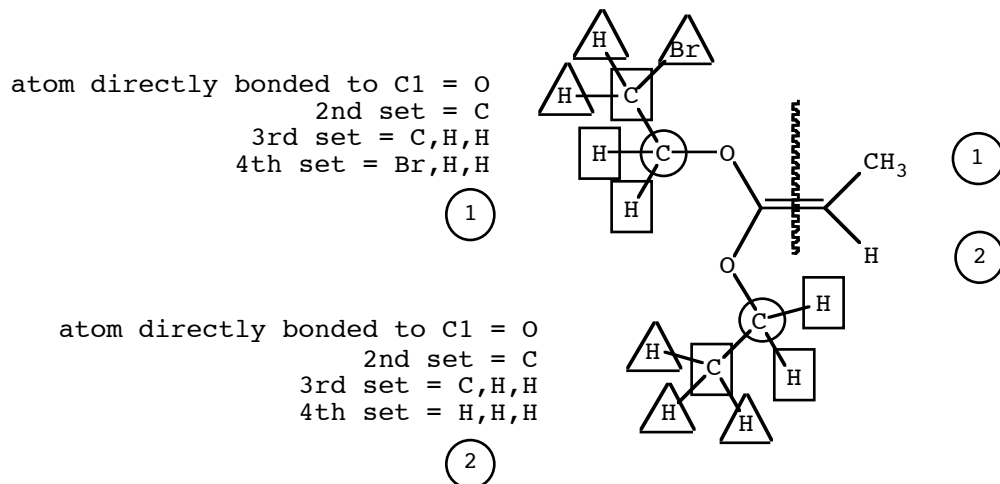
We now compare the atoms in each set one-by-one until a higher atomic-number atom can be identified: because the C in {C,H,H} has a higher atomic number than the first H in {H,H,H}, the double bond is assigned the *E* stereochemistry; the systematic name of the compound is (2*E*)-3-methyl-2-pentene.

Sometimes it's necessary to go out several sets of atoms before a stereochemical assignment can be made.

Example Consider the 1-(2-bromoethoxy)-1-ethoxy-1-propene structure below:

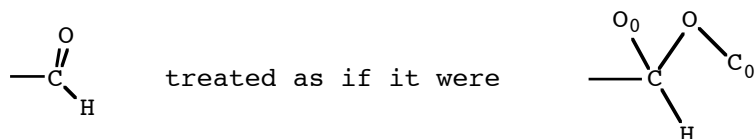


The ranking by atomic number at C2 is easy, but the ranking at C1 is anything but because we must consider several sets of atoms. The atoms directly bonded to C1 are both oxygens; the atoms bonded to the oxygens are both carbons; each of those carbons is in turn bonded to one carbon and two hydrogens; the fourth set finally allows the assignment of the *Z* stereochemistry to be made. The illustration below encloses the various sets of atoms in different markers.



### Treatment of multiple bonds in the CIP *E,Z* system

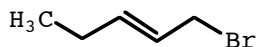
In the CIP *E,Z* system, multiple bonds are treated as an equivalent number of single bonds. For example, the carbon atom in the aldehyde group is treated as if it were bonded to two oxygen atoms rather than bonded to one oxygen atom by a double bond. In like fashion, the oxygen atom in the aldehyde group is treated as if it were bonded to two carbon atoms rather than bonded to one carbon atom by a double bond:



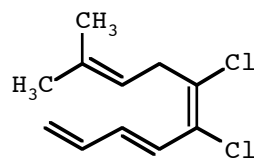
In the drawing above, the aldehyde carbon is pictured bonded to a real oxygen atom (O) and to a second oxygen atom (O<sub>0</sub>) that doesn't really exist but merely serves as a bookkeeping device of the CIP *E,Z* system. In like fashion, the aldehyde oxygen is pictured bonded to a real carbon atom (C) and to a second carbon atom (C<sub>0</sub>) that also merely serves a bookkeeping purpose. In the deconstruction of the aldehyde group pictured above, the atoms C<sub>0</sub> and O<sub>0</sub> are called phantom atoms.

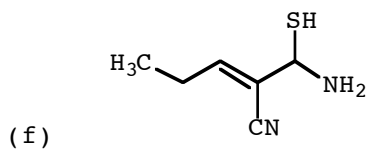
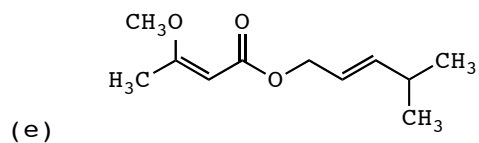
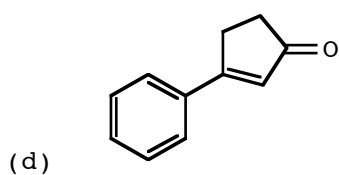
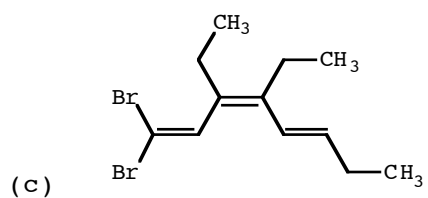
**Problem** Write the systematic name of these molecules; include the stereochemical descriptors "*E*" and "*Z*" where appropriate.

(a)



(b)





Answer (a) (2*E*)-1-bromo-2-pentene (b) (3*E*,5*Z*)-5,6-dichloro-9-methyl-1,3,5,8-decatetraene (c) (3*Z*,5*E*)-1,1-dibromo-3,4-diethyl-1,3,5-octatriene (d) (2*E*)-3-phenyl-2-cyclopenten-1-one (e) (2*E*)-4-methyl-2-pentenyl (2*Z*)-3-methoxy-2-buten-1-oate (f) (2*E*)-2-(1-amino-1-mercaptomethyl)-2-pentene-1-nitrile