Teacher: DR. SUBHANKAR SARDAR
Class : Semester-2
Paper: C4T: Organic Chemistry
Topic : General Treatment of Reaction Mechanism II (Tautomerism)

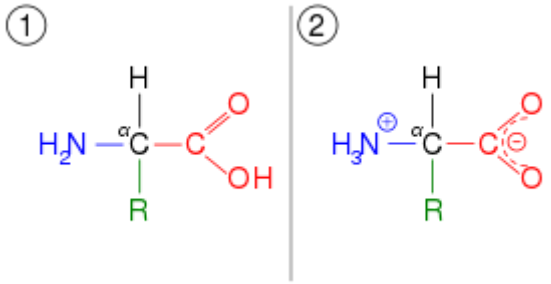
Comments: Read the highlighted parts of the notes thoroughly. This part is very important for final examination.

References:

1) Part-1: Wikipedia
2) Part-2: Internet
3) Part-3: Marchs advanced organic chemistry reactions mechanism

Tautomer

Tautomers (/ˈtɔːtəmər/)[1] are structural isomers (constitutional isomers) of chemical compounds that readily interconvert.[2][3][4] This reaction commonly results in the relocation of a proton. Tautomerism is for example relevant to the behavior of amino acids and nucleic acids, two of the fundamental building blocks of life.



The two tautomers of an amino acid: (1) neutral and (2) zwitterionic forms.

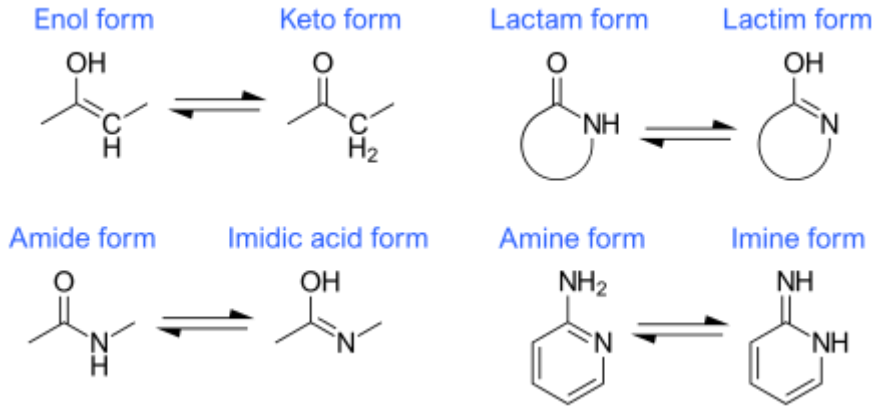
The concept of tautomerizations is called **tautomerism**. Tautomerism is also called desmotropism. The chemical reaction interconverting the two is called **tautomerization**.

Care should be taken not to confuse tautomers with depictions of "contributing structures" in chemical resonance. Tautomers are distinct chemical species and can be identified as such by their differing spectroscopic data,[5] whereas resonance structures are merely convenient depictions and do not physically exist.

Contents

Examples

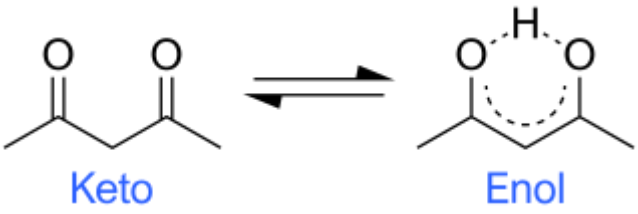
Tautomerization is pervasive in organic chemistry. It is typically associated with polar molecules and ions containing functional groups that are at least weakly acidic. Most common tautomers exist in pairs, which means that the proton is located at one of two positions, and even more specifically the most common form involves a hydrogen changing places with a double bond: H−X−Y=Z ⇌ X=Y−Z−H. Common tautomeric pairs



Some examples of tautomers

include:[6]

- ketone – enol: H−O−C=C ⇌ O=C−C−H, see keto–enol tautomerism
- enamine – imine: H−N−C=C ⇌ N=C−C−H
  - cyanamide – carbodiimide
  - guanidine – guanidine – guanidine: With a central carbon surrounded by three nitrogens, a guanidine group allows this transform in three possible orientations



Keto-enol tautomerization typically strongly favors the keto tautomer, but an important exception is the case of 1,3-diketones such as acetylacetone.

- amide – imidic acid: H−N−C=O ⇌ N=C−O−H (e.g., the latter is encountered during nitrile hydrolysis reactions)
  - lactam – lactim, a cyclic form of amide-imidic acid tautomerism in 2-pyridone and derived structures such as the nucleobases guanine, thymine, and cytosine
- imine – imine, e.g., during pyridoxal phosphate catalyzed enzymatic reactions
  - $R^1R^2C(=NCHR^3R^4) \rightleftharpoons (R^1R^2CHN=)CR^3R^4$
- nitro – *aci*-nitro (nitronic acid): $RR'HC–N^+(=O)(O^-) \rightleftharpoons RR'C=N^+(O^-)(OH)$
- nitroso – oxime: H−C−N=O ⇌ C=N−O−H
- ketene – ynol, which involves a triple bond: H−C=C=O ⇌ C≡C−O−H
- amino acid – ammonium carboxylate, which applies to the building blocks of the proteins. This shifts the proton more than two atoms away, producing a zwitterion rather than shifting a double bond: $H_2N−CH_2−COOH \rightleftharpoons H_3N^+−CH_2−CO_2^-$
- phosphite – phosphonate: $P(OR)_2(OH) \rightleftharpoons HP(OR)_2(=O)$ between trivalent and pentavalent phosphorus.

Prototropy

Prototropy is the most common form of tautomerism and refers to the relocation of a proton.[7] Prototropic tautomerism may be considered a subset of acid-base behavior. Prototropic tautomers are sets of isomeric protonation states with the same empirical formula and total charge. Tautomerizations are catalyzed by:

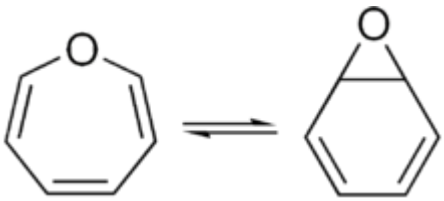
- bases, involving a series of steps: deprotonation, formation of a delocalized anion (e.g., an enolate), and protonation at a different position of the anion; and
- acids, involving a series of steps: protonation, formation of a delocalized cation, and deprotonation at a different position adjacent to the cation).

Two specific further subcategories of tautomerizations:

- Annular tautomerism is a type of prototropic tautomerism wherein a proton can occupy two or more positions of a heterocyclic system, for example, 1*H*- and 3*H*-imidazole; 1*H*-, 2*H*- and 4*H*-1,2,4-triazole; 1*H*- and 2*H*- isoindole.[8]
- Ring–chain tautomers occur when the movement of the proton is accompanied by a change from an open structure to a ring, such as the open chain and cyclic hemiacetal (typically pyranose or furanose forms) of many sugars.[6] (See Carbohydrate § Ring-straight chain isomerism.) The tautomeric shift can be described as H−O · C=O ⇌ O−C−O−H, where the "·" indicates the initial absence of a bond.

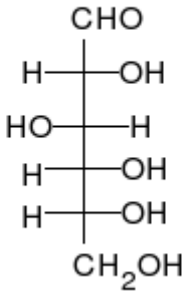
Valence tautomerism

Valence tautomerism is a type of tautomerism in which single and/or double bonds are rapidly formed and ruptured, without migration of atoms or groups.[9] It is distinct from prototropic tautomerism, and involves processes with rapid reorganisation of bonding electrons.



Oxepin – benzene oxide equilibrium

A pair of valence tautomers with formula C_6H_6O are benzene oxide and oxepin.[9][10]



Glucose can exist in both a straight-chain and ring form.

Other examples of this type of tautomerism can be found in bullvalene, and in open and closed forms of certain heterocycles, such as organic azides and tetrazoles,[11] or mesoionic münchnone and acylamino ketene.

Valence tautomerism requires a change in molecular geometry and should not be confused with canonical resonance structures or mesomers.

See also

- Fluxional molecule

References

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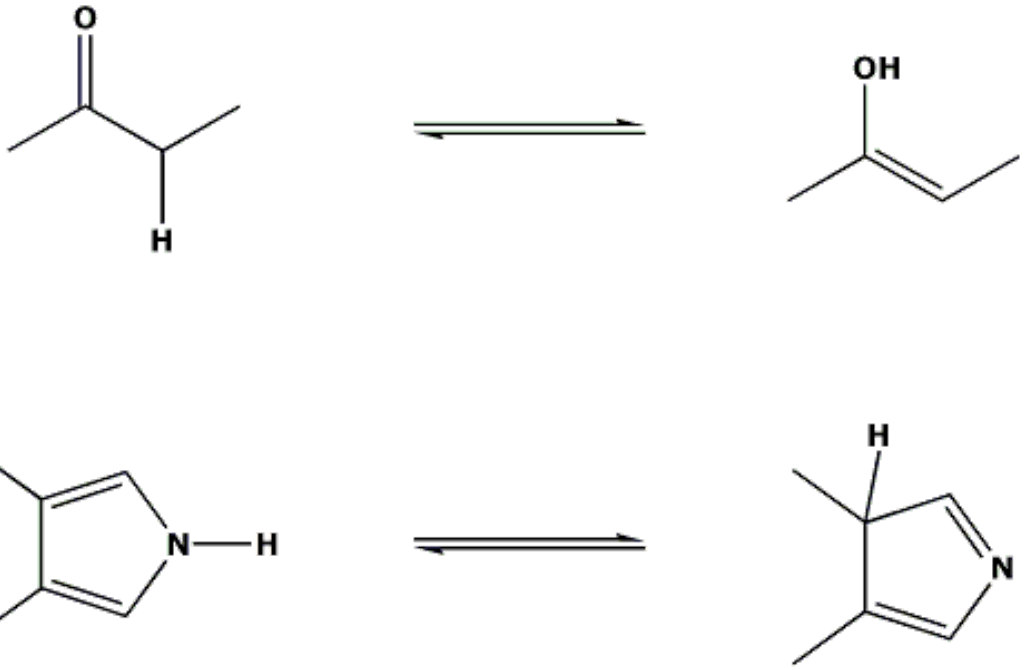
7. IUPAC, *Compendium of Chemical Terminology*, 2nd ed. (the "Gold Book") (1997). Online corrected version: (2006–) "Tautomerism (https://goldbook.iupac.org/T06252.html)". doi:10.1351/goldbook.T06252 (https://doi.org/10.1351%2Fgoldbook.T06252)

Tautomerism

Tautomers are isomers of a compound which differ only in the position of the protons and electrons. The carbon skeleton of the compound is unchanged. A reaction which involves simple proton transfer in an intramolecular fashion is called a tautomerism.
Keto-enol tautomerism is a very common process, and is acid or base catalysed. Typically the 'keto' form of the compound is more stable, but in some instances the 'enol' form can be the more stable.

Some examples of tautomerism:



NOTE: The equilibrium arrows above *do not* intend to show the *position* of the equilibrium, only that an equilibrium exists between the two forms.

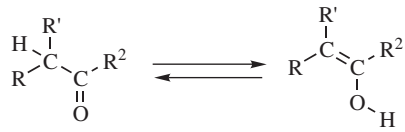
forms display no more charge separation than the main form. Muller and Mulliken call this *isovalent hyperconjugation*: Even here the main form contributes more to the hybrid than the others.

TAUTOMERISM[378]

There remains one topic to be discussed in our survey of chemical bonding in organic compounds. For most compounds, all the molecules have the same structure, whether or not this structure can be satisfactorily represented by a Lewis formula. But for many other compounds there is a mixture of two or more structurally distinct compounds that are in rapid equilibrium. When this phenomenon, called *tautomerism*,[379] exists, there is a rapid shift back and forth among the molecules. In most cases, it is a proton that shifts from one atom of a molecule to another.

Keto–Enol Tautomerism[380]

A very common form of tautomerism is that between a carbonyl compound containing an a hydrogen and its enol form:[381] Such equilibria are pH dependent, as in the case of 2-acetylcyclohexanone.[382]



Keto form **Enol form**

In simple cases ($R^2 = H$, alkyl, OR, etc.) the equilibrium lies well to the left (Table 2.1). The reason can be seen by examining the bond energies in Table 1.7.

[378]Baker, J.W. *Tautomerism*; D. Van Nostrand Company, Inc., New York, ***1934***; Minkin, V.I.; Olekhnovich, L.P.; Zhdanov, Y.A. *Molecular Design of Tautomeric Compounds*, D. Reidel Publishing Co.: Dordrecht, Holland, ***1988***.

[379]For reviews, see Toullec, J. *Adv. Phys. Org. Chem.* ***1982***, *18*, 1; Kołsov, A.I.; Kheifets, G.M. *Russ. Chem. Rev.* ***1971***, *40*, 773; ***1972***, *41*, 452–467; Forsén, S.; Nilsson, M., in Zabicky, J. *The Chemistry of the Carbonyl Group*, Vol. 2, Wiley, NY, ***1970***, pp. 157–240.

[380]The mechanism for conversion of one tautomer to another is discussed in Chapter 12 (reaction **12-3**).

[381]Capponi, M.; Gut, I.G.; Hellrung, B.; Persy, G.; Wirz, J. *Can. J. Chem.* ***1999***, *77*, 605. For a treatise, see Rappoport, Z. *The Chemistry of Enols*, Wiley, NY, ***1990***.

[382]Iglesias, E. *J. Org. Chem.*, ***2003***, *68*, 2680.

TABLE 2.1. The Enol Content of Some Carbonyl Compounds

Compound	Enol Content, %	References
Acetone	6×10^{-7}	383
$PhCOCH_3$	1.1×10^{-6}	384
Cyclopentanone	1×10^{-6}	385
CH_3CHO	6×10^{-5}	386
Cyclohexanone	4×10^{-5}	385
Butanal	5.5×10^{-4}	387
$(CH_3)_2CHCHO$	1.4×10^{-2}	388,387
Ph_2CHCHO	9.1	389
CH_3COOEt	No enol found[a]	385
CH_3COCH_2COOEt	8.4	390
$CH_3COCH_2COCH_3$	80	322
$PhCOCH_2COCH_3$	89.2	385
$EtOOCCH_2COOEt$	7.7×10^{-3}	385
$N{\equiv}C{-}CH_2COOEt$	2.5×10^{-1}	385
Indane-1-one	3.3×10^{-8}	391
Malonamide	No enol found	392

[a]Less than 1 part in 10 million.

The keto form differs from the enol form in possessing a C—H, a C—C, and a C=O bond, where the enol has a C=C, a C—O, and an O—H bond. The approximate sum of the first three is 359 kcal mol^{-1} (1500 kJ mol^{-1}) and of the second three is 347 kcal mol^{-1} (1452 kJ mol^{-1}). The keto form is therefore thermodynamically more stable by ~12 kcal mol^{-1} (48 kJ mol^{-1}) and enol forms cannot normally be isolated.[393] In certain cases, however, a larger amount of the enol form is present,

[383]Tapuhi, E.; Jencks, W.P. *J. Am. Chem. Soc.* **1982**, *104*, 5758; Chiang, Y.; Kresge, A.J.; Tang, Y.S.; Wirz, J. *J. Am. Chem. Soc.* **1984**, *106*, 460. See also, Hine, J.; Arata, K. *Bull. Chem. Soc. Jpn.* **1976**, *49*, 3089; Guthrie, J.P. *Can. J. Chem.* 1979, *57*, 797, 1177; Dubois, J.E.; El-Alaoui, M.; Toullec, J. *J. Am. Chem. Soc.* 1981, *103*, 5393; Toullec, J. *Tetrahedron Lett.* 1984, *25*, 4401; Chiang, Y.; Kresge, A.J.; Schepp, N.P. *J. Am. Chem. Soc.* **1989**, *111*, 3977.

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[390]Moriyasu, M.; Kato, A.; Hashimoto, Y. *J. Chem. Soc. Perkin Trans. 2* 1986, 515. For enolization of β-ketoamides, see Hynes, M.J.; Clarke, E.M. *J. Chem. Soc. Perkin Trans. 2* **1994**, 901.

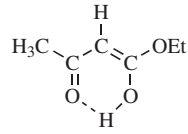
[391]Jefferson, E.A.; Keeffe, J.R.; Kresge, A.J. *J. Chem. Soc. Perkin Trans. 2* **1995**, 2041.

[392]Williams, D.L.H.; Xia, L. *J. Chem. Soc. Chem. Commun.* **1992**, 985.

[393]For reviews on the generation of unstable enols, see Kresge, A.J. *Pure Appl. Chem.* ***1991***, *63*, 213; Capon, B., in Rappoport, Z. *The Chemistry of Enols*, Wiley, NY, ***1990***, pp. 307–322.

and it can even be the predominant form.[394] There are three main types of the more stable enols:[395]

1. Molecules in which the enolic double bond is in conjugation with another double bond. Some of these are shown in Table 2.1. As the table shows, carboxylic esters have a much smaller enolic content than ketones. In molecules like acetoacetic ester (**142**), the enol is also stabilized by internal hydrogen bonding, which is unavailable to the keto form:



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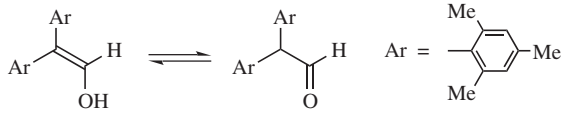
2. Molecules that contain two or three bulky aryl groups.[396] An example is 2,2-dimesitylethenol (**143**). In this case the keto content at equilibrium is only 5%.[397] In cases such as this, steric hindrance (p. 230) destabilizes the keto form. In **143**, the two aryl groups are ~120° apart, but in **144** they must move closer together (~109.5°). Such compounds are often called *Fuson-type enols*.[398] There is one example of an amide with a bulky aryl group [*N*-methyl bis(2,4,6-triisopropylphenyl)acetamide] that has a measurable enol content, in sharp contrast to most amides.[399]



143 **144**

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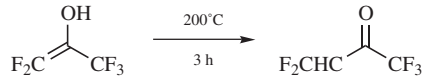
[398]First synthesized by Fuson, R.C.; see, for example, Fuson, R.C.; Southwick, P.L.; Rowland, S.P. *J. Am. Chem. Soc.* ***1944***, *66*, 1109.

[399]Frey, J.; Rappoport, Z. *J. Am. Chem. Soc.* ***1996***, *118*, 3994.

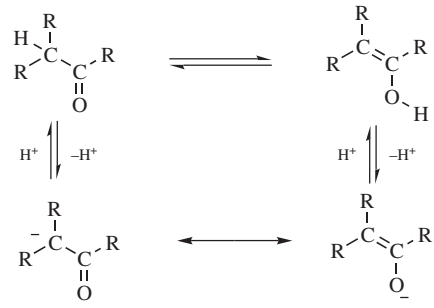
3. Highly fluorinated enols, such as **145**.[400]



145 **146**

In this case, the enol form is not more stable than the keto form (**146**). The enol form is less stable, and converts to the keto form upon prolonged heating). It can, however, be kept at room temperature for long periods of time because the tautomerization reaction (**12-3**) is very slow, owing to the electron-withdrawing power of the fluorines.

Frequently, when the enol content is high, both forms can be isolated. The pure keto form of acetoacetic ester melts at −39°C, while the enol is a liquid even at −78°C. Each can be kept at room temperature for days if catalysts, such as acids or bases, are rigorously excluded.[401] Even the simplest enol, vinyl alcohol $CH_2{=}CHOH$, has been prepared in the gas phase at room temperature, where it has a half-life of ∼30 min.[402] The enol $Me_2C{=}CCHOH$ is indefinitely stable in the solid state at −78°C and has a half-life of ∼24 h in the liquid state at 25°C.[403] When both forms cannot be isolated, the extent of enolization is often measured by NMR.[404]



147 **148**

[400]For a review, see Bekker, R.A.; Knunyants, I.L. *Sov. Sci. Rev. Sect. B* ***1984***, *5*, 145.
[401]For an example of particularly stable enol and keto forms, which could be kept in the solid state for more than a year without significant interconversion, see Schulenberg, J.W. *J. Am. Chem. Soc.* ***1968***, *90*, 7008.
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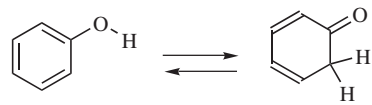
[403]Chin, C.S.; Lee, S.Y.; Park, J.; Kim, S. *J. Am. Chem. Soc.* ***1988***, *110*, 8244.
[404]Cravero, R.M.; González-Sierra, M.; Olivieri, A.C. *J. Chem. Soc. Perkin Trans. 2* ***1993***, 1067.

The extent of enolization[405] is greatly affected by solvent,[406] concentration, and temperature. Lactone enols, for example, have been shown to be stable in the gas phase, but unstable in solution.[407] Thus, acetoacetic ester has an enol content of 0.4% in water and 19.8% in toluene.[408] In this case, water reduces the enol concentration by hydrogen bonding with the carbonyl, making this group less available for internal hydrogen bonding. As an example of the effect of temperature, the enol content of pentan-2,4-dione, $CH_3COCH_2COCH_3$, was found to be 95, 68, and 44%, respectively, at 22, 180, and 275°C.[409] When a strong base is present, both the enol and the keto form can lose a proton. The resulting anion (the *enolate ion*) is the same in both cases. Since **147** and **148** differ only in placement of electrons, *they* are not tautomers, but canonical forms. The true structure of the enolate ion is a hybrid of **147** and **148** although **148** contributes more, since in this form the negative charge is on the more electronegative atom.

Other Proton-Shift Tautomerism

In all such cases, the anion resulting from removal of a proton from either tautomer is the same because of resonance. Some examples are:[410]

1. *Phenol–Keto Tautomerism.*[411]



Phenol **Cyclohexadienone**

For most simple phenols, this equilibrium lies well to the side of the phenol, since only on that side is there aromaticity. For phenol itself, there is no evidence for the existence of the keto form.[412] However, the keto form

[405]For a review of keto–enol equilibrium constants, see Toullec, J. in Rappoport, Z. *The Chemistry of Enols*, Wiley, NY, ***1990***, pp. 323–398.

[406]For an extensive study, see Mills, S.G.; Beak, P. *J. Org. Chem.* ***1985***, *50*, 1216. For keto–enol tautomerism in aqueous alcohol solutions, see Blokzijl, W.; Engberts, J.B.F.N.; Blandamer, M.J. *J. Chem. Soc. Perkin Trans. 2* ***1994***, 455; For theoretical calculations of keto–enol tautomerism in aqueous solutions, see Karelson, M.; Maran, U.; Katritzky, A.R. *Tetrahedron* ***1996***, *52*, 11325.

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[408]Meyer, K.H. *Leibigs Ann. Chem.* ***1911***, *380*, 212. See also, Moriyasu, M.; Kato, A.; Hashimoto, Y. *J. Chem. Soc. Perkin Trans. 2* ***1986***, 515.

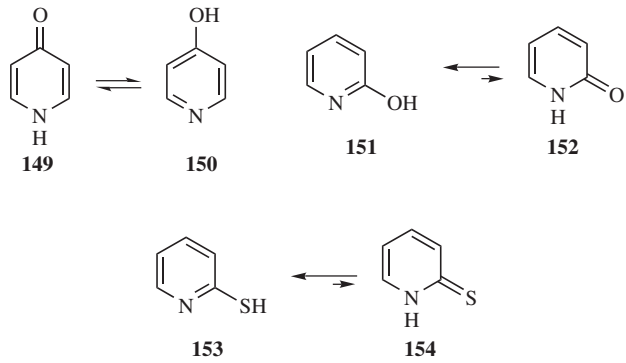
[409]Hush, N.S.; Livett, M.K.; Peel, J.B.; Willett, G.D. *Aust. J. Chem.* ***1987***, *40*, 599.

[410]For a review of the use of X-ray crystallography to determine tautomeric forms, see Furmanova, N.G. *Russ. Chem. Rev.* ***1981***, *50*, 775.

[411]For reviews, see Ershov, V.V.; Nikiforov, G.A. *Russ. Chem. Rev.* ***1966***, *35*, 817; Forsén, S.; Nilsson, M., in Zabicky, J. *The Chemistry of the Carbonyl Group*, Vol. 2, Wiley, NY, ***1970***, pp. 168–198.

[412]Keto forms of phenol and some simple derivatives have been generated as intermediates with very short lives, but long enough for spectra to be taken at 77 K. Lasne, M.; Ripoll, J.; Denis, J. *Tetrahedron Lett.* ***1980***, *21*, 463. See also, Capponi, M.; Gut, I.; Wirz, J. *Angew. Chem. Int. Ed.* ***1986***, *25*, 344.

becomes important and may predominate: (*1*) where certain groups, such as a second OH group or an N=O group, are present;[413] (*2*) in systems of fused aromatic rings;[414] (*3*) in heterocyclic systems. In many heterocyclic compounds in the liquid phase or in solution, the keto form is more stable,[415] although in the vapor phase the positions of many of these equilibria are reversed.[416] For example, in the equilibrium between 4-pyridone (**149**) and 4-hydroxypyridine (**150**), **149** is the only form detectable in ethanolic solution, while **150** predominates in the vapor phase.[416] In other heterocycles, the hydroxy-form predominates. 2-Hydroxypyridone (**151**) and pyridone-2-thiol (**153**)[417] are in equilibrium with their tautomers, 2-pyridone **152** and pyridine-2-thione **154**, respectively. In both cases, the most stable form is the hydroxy tautomer, **151** and **153**.[418]



149 **150** **151** **152**

153 **154**

2. *Nitroso–Oxime Tautomerism.*

The equiblirum shown for formaldhyde oxime and nitrosomethane illustrates this process.[419] In molecules where the products are stable, the equilibrium lies far to the right, and as a rule nitroso compounds are stable only when there is not a hydrogen.

[413]Ershov, V.V.; Nikiforov, G.A. *Russ. Chem. Rev.* ***1966***, *35*, 817. See also, Highet, R.J.; Chou, F.E. *J. Am. Chem. Soc.* ***1977***, *99*, 3538.

[414]See, for example, Majerski, Z.; Trinajstić, N. *Bull. Chem. Soc. Jpn.* ***1970***, *43*, 2648.

[415]For a monograph on tautomerism in heterocyclic compounds, see Elguero, J.; Marzin, C.; Katritzky, A.R.; Linda, P. *The Tautomerism of Heterocycles*, Academic Press, NY, ***1976***. For reviews, see Katritzky, A.R.; Karelson, M.; Harris, P.A. *Heterocycles* ***1991***, *32*, 329; Beak, P. *Acc. Chem. Res.* ***1977***, *10*, 186; Katritzky, A.R. *Chimia*, ***1970***, *24*, 134.

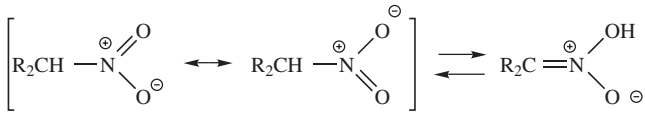
[416]Beak, P.; Fry, Jr., F.S.; Lee, J.; Steele, F. *J. Am. Chem. Soc.* ***1976***, *98*, 171.

[417]Moran, D.; Sukcharoenphon, K.; Puchta, R.; Schaefer III, H.F.; Schleyer, P.v.R.; Hoff, C.D. *J. Org. Chem.* ***2002***, *67*, 9061.

[418]Parchment, O.G.; Burton, N.A.; Hillier, I.H.; Vincent, M.A. *J. Chem. Soc. Perkin Trans. 2* ***1993***, 861.

[419]Long, J.A.; Harris, N.J.; Lammertsma, K. *J. Org. Chem.* ***2001***, *66*, 6762.

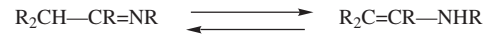
3. *Aliphatic Nitro Compounds Are in Equilibrium with Aci Forms.*



Nitro form Aci form

The nitro form is much more stable than the aci form in sharp contrast to the parallel case of nitroso–oxime tautomerism, undoubtedly because the nitro form has resonance not found in the nitroso case. Aci forms of nitro compounds are also called nitronic acids and azinic acids.

4. *Imine–Enamine Tautomerism.*[420]



Imine Enamine

Enamines are normally stable only when there is no hydrogen on the nitrogen ($R_2C{=}CR{-}NR_2$). Otherwise, the imine form predominates.[421] The energy of various imine–enamine tautomers has been calculated.[422] In the case of 6-aminofulvene-1-aldimines, tautomerism was observed in the solid state, as well as in solution.[423]

5. *Ring-Chain Tautomerism.* Ring-chain tautomerism[424] occurs in sugars (aldehyde vs. the pyranose or furanose structures), and in γ-oxocarboxylic acids.[425] In benzamide carboxaldehyde, **156**, whose ring-chain tautomer is **155**, the equilibrium favors the cyclic form (**156**).[426] Similarly, benzoic acid 2-carboxyaldehyde (**157**) exists largely as the cyclic form (**158**).[427] In these latter cases, and in many others, this tautomerism influences chemical reactivity. Conversion of **157** to an ester, for example, is difficult since most standard methods lead to the OR derivative of **158** rather than the ester of **157**. Ring-chain tautomerism also occurs in spriooxathianes,[428] and in

[420]For reviews, see Shainyan, B.A.; Mirskova, A.N. *Russ. Chem. Rev.* ***1979***, *48*, 107; Mamaev, V.P.; Lapachev, V.V. *Sov. Sci. Rev. Sect. B.* ***1985***, *7*, 1. The second review also includes other closely related types of tautomerization.

[421]For examples of the isolation of primary and secondary enamines, see Shin, C.; Masaki, M.; Ohta, M. *Bull. Chem. Soc. Jpn.* ***1971***, *44*, 1657; de Jeso, B.; Pommier, J. *J. Chem. Soc. Chem. Commun.* ***1977***, 565.

[422]Lammertsma, K.; Prasad, B.V. *J. Am. Chem. Soc.* ***1994***, *116*, 642.

[423]Sanz, D.; Perez-Torralba, M.; Alarcon, S.H.; Claramunt, R.M.; Foces-Foces, C.; Elguero, J. *J. Org. Chem.* ***2002***, *67*, 1462.

[424]For a monograph, see Valters, R.E.; Flitsch, W. *Ring-Chain Tautomerism*, Plenum, NY, ***1985***. For reviews, see Valters, R.E. *Russ. Chem. Rev.* ***1973***, *42*, 464; ***1974***, *43*, 665; Escale, R.; Verducci, J. *Bull. Soc. Chim. Fr.*, ***1974***, 1203.

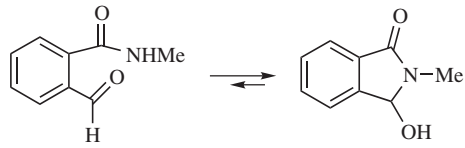
[425]Fabian, W.M.F.; Bowden, K. *Eur. J. Org. Chem.* ***2001***, 303.

[426]Bowden, K.; Hiscocks, S.P.; Perjéssy, A. *J. Chem. Soc. Perkin Trans. 2* ***1998***, 291.

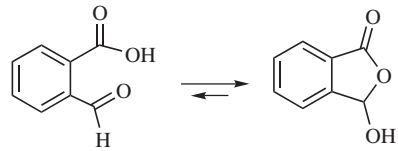
[427]Ring-chain tautomer of benzoic acid 2-carboxaldehdye.

[428]Terec, A.; Grosu, I.; Muntean, L.; Toupet, L.; Plé, G.; Socaci, C.; Mager, S. *Tetrahedron* ***2001***, *57*, 8751; Muntean, L.; Grosu, I.; Mager, S.; Plé, G.; Balog, M. *Tetrahedron Lett.* ***2000***, *41*, 1967.

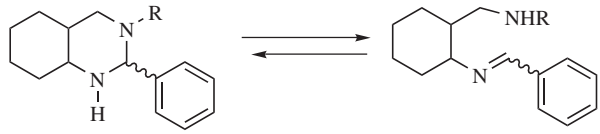
decahydroquinazolines, such as **159** and **160**,[429] as well as other 1,3-heterocycles.[430]



155 **156**

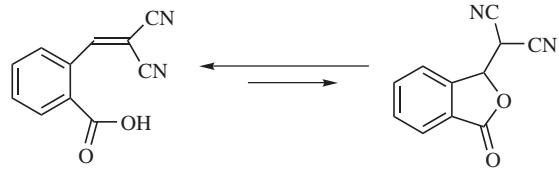


157 **158**



159 **160**

There are many other highly specialized cases of proton-shift tautomerism, including an internal Michael reaction (see **15**-**24**) in which 2-(2,2-dicyano-1-methylethenyl)benzoic acid (**161**) exists largely in the open chain form rather an its tautomer (**162**) in the solid state, but in solution there is an increasing amount of **162** as the solvent becomes more polar.[431]



161 **162**

Valence Tautomerism

This type of tautomerism is discussed on p. 105.

[429]Lazar, L.; Goblyos, A.; Martinek, T.A.; Fulop, F. *J. Org. Chem.* ***2002***, *67*, 4734.
[430]Lázár, L.; Fülöp, F. *Eur. J. Org. Chem.* ***2003***, 3025.
[431]Kolsaker, P.; Arukwe, J.; Barcóczy, J.; Wiberg, A.; Fagerli, A.K. *Acta Chem. Scand. B* ***1998***, *52*, 490.