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NMR Spectroscopy

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Tech Essay: NMR Spectroscopy

Nuclear Magnetic Resonance, also known as NMR, is often described by chemists as one of the most useful pieces of equipment to have in the lab. Chemists often use NMR technology to determine the structure of different chemical compounds. Although this is its primary use, NMR can also be used in medicine. Magnetic Resonance Imaging, which is also known as MRI uses the same technology as NMR.

NMR was first used in 1938 by Isidor Rabi and the process was refined and improved in 1946 by Felix Bloch and Edward Purcell. In order to understand how the NMR works, you first need to understand the structure of an atom. An atom is composed of a nucleus that neutrons, which do not have a charge, and protons, which have a positive charge. Orbiting around the nucleus are electrons, which contain a negative charge. There are two main types of NMR spectroscopy, ^{1}H (proton) and ^{13}C (carbon-13). These two methods work because there is an unequal number of protons and neutrons in the nucleus of the atoms. This allows the nuclei to act as magnets that were spinning on an axis. When these atoms are placed in a very strong magnetic field, the nuclei absorb energy. The data of this absorption is quantized and, through the use of a computer, a NMR spectrum is produced which looks just like the attached spectrums.

We start out by mixing out chemical with a solution of tetramethylsilane, also known as TMS. The TMS is used as a reference point on the spectrum because its peak is set at zero. TMS is also useful for NMR because it is highly volatile, meaning that it easily evaporates allowing the sample to be easily recovered. Next we put the solution into the NMR spectrometer

and turn on the magnet. The magnet consists of coiled wire with current flowing through it that produces a large magnetic field. Due to the amount of heat that is produced by the magnet, it is surrounded by two baths, one of liquid helium, and the other of liquid nitrogen. However, the area in which the sample is inserted is kept at room temperature. The sample is also pulsed with a radio frequency by a frequency synthesizer. This causes the magnetic field of the proton to shift. As the field shifts between its different states, the signal is read and sent to a computer by an analog to digital converter.

On the computer you receive an NMR spectrum much like the one attached. To interpret the spectrum and determine the structure of a chemical, one must understand what all of the peaks correspond to in the spectrum. Once the TMS spike is set to zero, the location on the x-axis, also known as the chemical shift, gives you information about the structure and environment of the protons producing that signal. The chemical shift is determined by the relative electron density around that atom. The lower the electron density of an atom, the more deshielded the atom is from the magnetic field. This gives it a higher parts per million in the NMR spectrum. For example if a set of peaks has a chemical shift of 2.1-2.6 it is probably a hydrogen proton on a ketone. However, if the chemical shift of the peak is 9.5-10.5 it is probably attached to an aldehyde. On the ^{1}H spectrum the integral of the each spike represents the ratio of the numbers of hydrogen ions that produce each signal. Coupling, also known as signal splitting, is caused when nearby hydrogen protons of the group of protons currently being observed splits the energy levels of the observed protons. This gives us multiple peaks for the same signal. Coupling consistently occurs in NMR spectroscopy and can, therefore, be used to help determine the molecular structure. The rule with coupling is n+1 where n is the number of hydrogen protons that are nearby the ones producing the signal. Therefore, if there are three

peaks for one signal, then those protons producing the signal are next to two protons. Since we usually know or have predetermined the molecular formula of our sample, we can use the chemical shift, integration, and coupling effect to determine the arrangements of the hydrogen protons in our sample.

Another spectrum that is used is the ^{13}C (carbon-13) spectrum. Peaks that occur with a greater chemical shift and a higher parts per million are bonded to more electronegative elements such as oxygen or chlorine. The main difference between the ^{1}H and the ^{13}C spectrums is that the peaks in the ^{13}C spectrum are not coupled. Therefore, each peak corresponds to one carbon atom. By looking at the chemical shift of each carbon, you can speculate what is bonded to each one. When the ^{1}H and the ^{13}C spectrums are compared to each other, it becomes quite simple to determine the molecular structure of your sample.

NMR has played a large role in drug design and discovery. Not only can it determine and characterize the sample, but it can also give affinity information on the drug. More people have seen an NMR than they may realize. If a person has ever received a MRI (magnetic resonance imaging), then they were placed inside a large NMR. The only reason that MRI is not called NMR is because people felt that the word “nuclear” would defer people from using it on them. An MRI is much safer than an x-ray because it does not use dangerous ionizing radiation. It also does not need potentially harmful chemicals to provide contrast in the image. When the magnetic field excites the protons in the body tissues, specifically in the water molecules of body tissues, the color and brightness of the image is determined by the number of protons at that particular place and the proton relaxation time. Since humans are approximately 70% water, MRI has proven to be monumental in the locating of tumors, lesions, and edemas since it is able to differentiate between fluid and solid areas in the body. Current research with MRI is with the

observation of signals from ^{31}P. This will focus primarily on ATP and ADP and will provide researchers a noninvasive way to follow cellular metabolism. ATP is the main source of energy for the cell. This will also help to locate tumors due to their greatly increased metabolic rate.

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