Chemical significance of an arrow

WHAT IS there in an arrow? It is simple, looks insignificant... yet appears in most scientific publica-
ns; whether mathematics, physics, emistry or biology. It exists as a sym- l in the word processing software d is perhaps the most often used no- ion by scientists apart from the usu- nathematical symbols, +, -, x, and =. is note is on this ubiquitous symbol particularly in relation to emistry.

Chemists employ a simple state- int, $A + B \rightarrow C$, to represent a chem- l reaction. The '+' symbolises the t that A and B 'combine' and the '$\rightarrow$' nds for 'it yields'.

Thus the equation written above is a nplete sentence or a chemical state- nt. The sentence would be, 'A com- es with B to yield C'. The first son to write this kind of sentences the father of the atomic hypothe- John Dalton (1803). He preferred ements in English and did not use mathematical form mentioned ve. Chemistry today is full of these thematical statements, and the st of chemists is to find more of m.

The arrow separates two distinct ds of species, the reagents and ducts; whereas reagents are enti- , which react, and products are se which form. If we were to start a ney into the reaction, only A and B exist in the beginning and C alone ld be present at the end.

This way in which a reaction is rep- ented combines some of the funda- ntal laws of chemistry. These are theories concerning the mass bal- e in reactions. The amount of A and mass terms will be equal to the unt of C formed. The reaction C + $\rightarrow CO_2$ means that one unit of C and unit of O_2 combine to form one of CO_2. The units here are, gram n in the case of carbon, and gram e in the case of O_2 and CO_2. Thus in s terms we have 12 g of C + 32 g of $\rightarrow$ 44 g of CO_2, the grams refer to the ective atomic/molecular quanti- Therefore, hidden in this equation e laws of mass action stating that if atom combines with another, it ld do so only in a certain propor- of their atomic/molar mass.

details this law will take several es (which have been the central ts of discussion in the early atomic but there is a definite ratio be- n the reagents. The reaction need e represented only as $A + B \rightarrow C$, it be $aA + bB \rightarrow cC$, where a, b and c imple integers. There can be more ies on either side of the arrow.

is form of representation is im- ble without the atomic view of matter. When one states that the reaction is with 12 grams of C, one actually means the reaction of 602000000000000000000000 atoms (the Avogadro number) of carbon reacting with that many O_2 molecules to form the same number of CO_2 molecules.

The arrow also signifies equality, as mentioned in relation to the mass balance. The mass equality was the issue of concern to Dalton, not very much the fact that C is formed from A and B. This equality actually extends much beyond the mass. If represented in other ways, it also means the balance of electrons.

The state of the participating atoms/ molecules also enter into the equation so that it can be $A(g) + B(l) \rightarrow C(s)$, where g, l and s represent the physical states of the constituents concerned. As chemical reactions involve energy changes, as is evident in the kitchen, the extent of energy change occurring is also indicated as in, $A(g) + B(l) \rightarrow C(s)$ ΔH= xxx, where ΔH is the amount of heat change involved. Various kinds of parameters representing the energy change can also come into the reaction, with their appropriate notations.

As one can see, the atomic view of matter is hidden in these equations and therefore, we owe a lot to Dalton for these representations.

However, the person who first these 'A + B' notations is Berzelius. In the *Annals of Philosophy* articles (1813 and 1814), Berzelius describes how chemical reactions can be conceived like mathematical formulae. The representations, 1 atom of A + 1 atom of B = 1 atom of C, is due to Dalton who did not consider it better to represent the chemical equation as a formula, as in $aA + bB \rightarrow$ products (*A new system of chemical philosophy, 1808*). The arrow is not found in the original papers of either of them and it appears to have got into chemistry much later. There are conditions, which govern chemical reactions. Temperature often increases the rate at which products are formed.

Sometimes measurable quantities of products are formed only when the temperature is high. Some reactions occur when there is light.

All of these conditions of chemical reactions are put right on top of the arrow in order that $A + B \xrightarrow{condition} C$. Sometimes the reaction occurs in the presence of another material, which enhances the speed of reaction -a catalyst- which is placed over the arrow. The reaction then becomes

$A + B \xrightarrow{catalyst} C$. The conditions and other participating entities become so important that often there are many parameters which go over (and sometimes under!) the arrow.

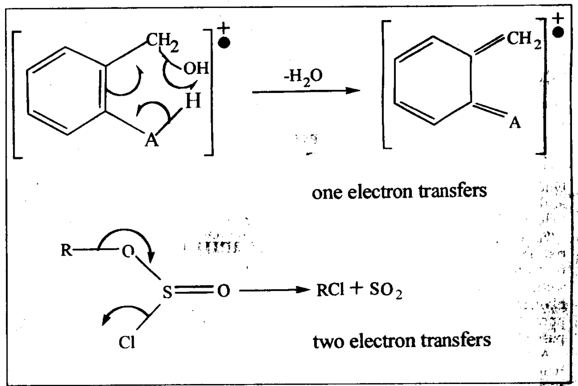
The early masters thought that the reaction is complete and products form when reactants react. The concept of chemical equilibrium came in much later. Papers of Guldberg and Waage over a period of 1867 to 1879 gave foundations to chemical equilibrium and the essence of these papers is the 'law of mass action' stating that the velocity of a reaction is proportion to the concentrations of the reacting species. The early experiments on kinetics (a branch of chemistry involved with the study of speed of reaction) were already available, although the kinetic equations as we know today were not proposed.

The experiments of Whilhelmy on kinetics measurements were published in *Annalen der Physik and Chemie* (1850).

When there is an equilibrium, a state of apparent constancy, the arrow in between the reactants and products become double sided so that, $A + B \leftrightarrow C$ or commonly nowadays, $A + B \rightleftarrows C$, or even $A + B \rightleftharpoons C$. The assumption is that the reaction is never complete in the sense that there is always A, B and C in the system even after infinite time. The amount of A, B and C are fixed depending on the 'thermodynamic' properties of all these entities. There is no way to change the equilibrium concentration at a given temperature.

The arrow also finds use in representing the mechanism of the reaction. The regular arrow often becomes a curved one in such cases.

The arrow A $\curvearrowright$ B would mean a two electron transfer and as the bond is made with two electrons, the bond between A and B disappears in this event. To distinguish this from one electron transfer, we have a fishhook arrow for this latter process. Both these arrows are very common in gas phase electron transfer processes, such as those in mass spectrometers. Some of these arrows taken from organic chemistry examples are given below:



Arrow is one of the most often used mathematical notations

The way in which an arrow is represented differs considerably depending on the situation. The arrow is of different lengths and curvatures, all means the same. It originates from the site of the electron transfer to the end.

As chemistry advanced, the arrow got into all its branches. In nuclear chemistry, the arrow would indicate nuclear processes, reactions may be between elementary particles or between these particles and nuclei.

In biochemistry the arrow may be placed between large polymeric molecules hundreds of thousand of times heavier than hydrogen and reactions may be very complex. They may not even be reactions in the conventional sense as in the case of an enzyme catalysis.

Processes may happen between molecules and macroscopic objects such as surfaces, as in catalysis. Some of the important reactions scientists are concerned with today may not be reactions at all, such as the formation of a molecular bundle from the constituent molecules. The reactions today may not occur always in a glass bottle. They may be in plasmas, flames, arcs or laser beams; still all of them would use an arrow.

An arrow would mean a pointer to some, an indicator on the road, a direction of flow; but in chemistry it is associated with change and all aspects of it.

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