‘All science is either physics or stamp collecting’

This is a quote attributed to Ernest Rutherford, a man who is considered the father of nuclear physics, a scientist who established the nuclear structure of the atom discovered alpha and beta rays and proposed the laws of radioactive decay: a physicist whose research and discoveries shaped the development of modern science and perhaps is considered one of the greatest experimental physicists of all time, and yet when he won a Nobel Prize in 1908 he won it for Chemistry.

For a man who, at first glance, appears to be sneering at all things not physics, the irony that his prize was **“for his researches concerning the disintegration of elements and the chemistry of radioactive substances.”** [1] was not even lost on the prize winner himself who is quoted as saying: “**I must confess it was very unexpected and I am very startled at my metamorphosis into a chemist.”** [2]

This blurred distinction between what is physics and what is not, therefore, adds complexity to a quote that at first glance seems simple to form an opinion. When Rutherford comments on what science and physics are, there can be a misinterpretation of what exactly science is, and what parts of science are defined in Rutherford’s categorisation of physics.

What is science? What is physics?

The word science itself is derived from the Latin word ‘scientia’, from the verb ‘scire’ meaning to know or to understand; and essentially in the widest terms the word science does mean the pursuit of knowledge, it the desire to understand the world around us. More specifically science is defined as *“the study of the nature and behaviour of the physical universe, based on observation, experiment, and measurement”* and “*the knowledge obtained by these methods”* [3]. This idea that science is knowledge acquired by systematic investigations is common through all definitions, and therefore from here onwards in this essay this is how I will consider science.

So, what parts of this *“study… of the physical universe”* is classified as physics? To try and define precisely what is physics seems almost demeaning to the science. To me, trying to define physics is to put a constantly expanding and changing field of research into a box and then flattening said box. However, to truly discuss this quotation it does seem necessary to try and define some parameters on what physics is, if only so we can discuss what physics isn’t.

Physics is defined in the dictionary as *“the branch of science concerned with the properties of matter and energy and the relationships between them”* [4]. To affirm this definition, let us consider the work of one of histories’ most famous physicists – Isaac Newton.

Newton’s Laws of Motion

Isaac Newton was a revolutionary physicist whose work on the laws of motion and gravity revolutionised modern science and is still used to this day.

Newton created three laws of motion to show the relationship between the forces applied on an object and the object’s subsequent motion.

First Law - states that *“if a body is at rest or moving at a constant speed in a straight line, it will remain at rest or keep moving in a straight line at constant speed unless it is acted upon by a force.”* [5]

For example, centripetal force.

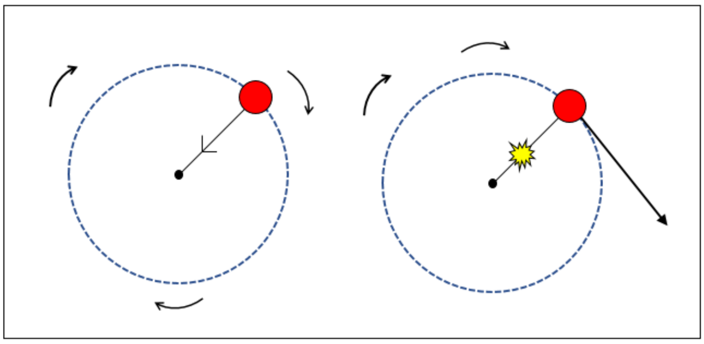

Figure 1 – the motion of an orbiting object in a straight line when forces are removed

The tension in a string travelling in a circular orbit with a mass attached to the end is given by the equation, T= $\frac{mv^2}{r}$, where m is mass of the object, v is its velocity and r is the radius of the circular path. However, due to Newton's First Law if the string snaps then the mass will continue a straight line path in the direction it was travelling at the instant that the string broke (as shown in the illustrations). This straight line motion is an example of Newton's First Law when the constraining force, the tension, is removed.

Second Law - states that *"the time rate of change of the momentum of a body is equal in both magnitude and direction to the force imposed on it."* [5]

Newton's Second Law is neatly summarised in the equation:

F = ma

Where **F** is the net force acting on an object, **m** is the mass of an object and **a** is the object's acceleration.

Third Law – states that *"when two bodies interact, they apply forces to one another that are equal in magnitude and opposite in direction."* [5]

For example, a box sitting on the floor exerts the force of its own weight on the floor, but the floor itself also applies an equal and opposite force on the box. This occurs because of the deformation of the material of the floor caused by the weight of the box, therefore just like a spring the floor 'pushes back'. This force is known as the normal contact force.

<u>Is it Physics?</u>

We now return to our original definition of physics and refer to Newton's work (which is globally known and accepted as a clear work of physics).

Physics – "the branch of science concerned with the properties of matter and energy and the relationships between them."

Quite clearly it can be seen that Newton's work is concerned with the relation between the forces applied on an object, and therefore the energy, and the properties of said object. Therefore, using this definition, Newton's 'science' is physics and Newton's physics is invaluable to developing science and so incredibly important, and hence - to rephrase Rutherford - Newton was no stamp collector.

What about Chemistry?

We now apply the same process to the work of an established chemist, Henry Louis Le Chatelier, and see whether there is science outside physics.

Le Chatelier's most famous work is on dynamic equilibrium which came to be known as Le Chatelier's principle. This principle states *"if a dynamic equilibrium is disturbed by changing the conditions, the position of equilibrium moves to counteract the change."* [6]

A famous example of Le Chatelier's principle applied to a practical situation is in the Haber Process, for the manufacture of ammonia.

$$N_{2\,(g)} + 3H_2 \leftrightarrow 2NH_3$$

In the reaction mixture, these two competing reactions are taking place at the same time, so the ammonia molecules decompose into the original reactants, as fast as they are formed. Hence, a dynamic equilibrium is reached. Therefore, Le Chatelier's Principle can be applied so that the reaction favours the production of ammonia.

<u>Changing Pressure</u>

The reactants, N_2 and $3H_2$ make up 4 moles of substance, while there are only 2 moles of the product NH_3. This means the reactants are at a greater pressure than the product. Therefore, if the pressure of the system is increased the equilibrium position shifts to the right in order to oppose this increase in pressure as the forward reaction produces fewer molecules.

<u>Changing Temperature</u>

The forward reaction has a ΔH value of $-92kJmol^{-1}$ and therefore is exothermic, while the backward reaction has a ΔH value of $+92kJmol^{-1}$ and is therefore endothermic. So, decreasing the temperature of the reaction favours the production of ammonia (although the rate of reaction will be lowered significantly so that if the temperature is too low it is no longer economically viable).

<u>Changing Concentration</u>

If the ammonia is produced in a piece of equipment so that the ammonia is continually removed from the system, then the system will never reach equilibrium. So, to oppose this change the equilibrium position shifts to the right to favour the production of ammonia.

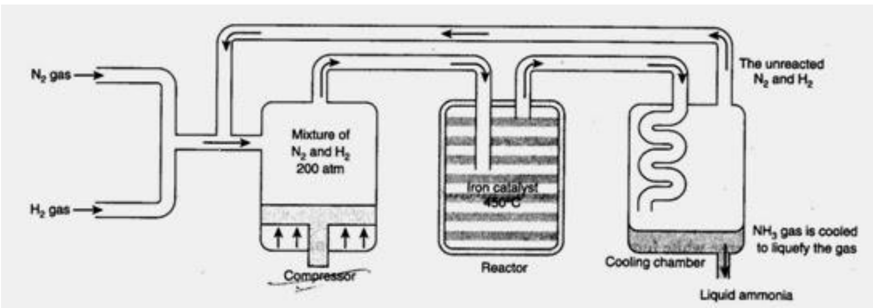

Figure 2 – a simplified ammonia reactor[7]

This shows a simplified ammonia reactor, with increased pressure, a controlled temperature and liquid ammonia being removed continuously through the process. In industry, ammonia is removed easily from the system since it has the highest boiling point and hence condenses first.

So here we have a piece of science that is essential, for example for fertilisers, in its applied uses and in its own scientific value. It is chemistry and it is not any form of classification or 'stamp collecting' so Rutherford has been disproved. Or has he?

If we return to our definition Physics (*the branch of science concerned with the properties of matter and energy and the relationships between them)* we can see that Le Chatelier's Principle can itself be classified as physics. In the discussion of the Haber Process we look at the properties of the reversible reactions, and the properties of the chemicals, or 'matter' that is involved, and we look at the relationship between these properties and the energy put into the reaction. For example, to create the higher pressure, a significant amount of energy is put into the process.

From here, it seems as if you could twist most scientific work and make it fit into our parameters of physics. Chemistry is the study of how substances react together, which in turn comes down to the application of Quantum Mechanics, which can be shown through **the Pauli Exclusion Principle.**

<u>The Pauli Exclusion Principle</u>

This Principle states that *"assertion that no two electrons in an atom can be at the same time in the same state or configuration"* **[8]**

And so, two electrons in an atom can have same n, l and m_l values, but must have a different spin value (m_s). Where **n** is the principle quantum number (must be a positive whole number value) and represents the energy level of the electron, **l** is the angular momentum quantum number (value from 0… (n-1)) and describes the shape of the orbital (e.g. l = 0, it is a spherical s-orbital), $\boldsymbol{m_l}$ is the magnetic quantum number (value from -l … l) and this determines how many orbitals there are, of a type, per energy level and $\boldsymbol{m_s}$ the spin quantum number, which must be $\frac{1}{2}$ or $-\frac{1}{2}$.

The Principle accounts for the existence of electron shells and therefore goes on to explain the Periodic Table.

Furthermore, Biology can be seen as the application of Chemistry to living things (and sometimes even the application of Physics). For example, by considering bones and joints as forces and levers. With this all being true, Physics is shown to be the most fundamental science and anything else is the collating of results – or 'stamp collecting'.

<u>Stamp Collecting</u>

The problem with Rutherford's quotation, is the arrogance that surrounds it. When read the immediate impression is that Rutherford is sneering at all the so called 'stamp collectors'. From the analogy it is reasonable to assume that by stamp collecting he means classification or data collection, which was carried out by many scientists in Rutherford's time. But I would argue that the classification that was occurring was essential to science going forwards. Take for example, the work of Dmitri Mendeleev.

Mendeleev – the Stamp Collector?

Dmitri Mendeleev was close to being a contemporary of Rutherford's, dying just before Rutherford received his Nobel prize, and in fact there was a push to try and award him the Nobel Prize for Chemistry in both 1906 and 1907 just before he died, for his work on the Periodic System, the two years previous to the year when Rutherford won his Nobel prize for Chemistry.

Mendeleev's most notable achievement is that of the classification of the Periodic Table. He placed the elements in order of atomic weight, and found that there were patterns of periodicity and similar properties of elements in the same group as each other. Perhaps most notably, Mendeleev left gaps in his table for elements that were yet to be discovered and then went onto predict the properties of these 'missing' elements. These predictions were proven true as each element was discovered. This led to Mendeleev being considered the founder of the periodic law and the beginning of the periodic table as we see it today.

The periodic table has been essential for almost all scientific development since its creation by Mendeleev in 1871 and as science goes forward in modern society. Therefore, it cannot be right that Rutherford would look down upon Mendeleev and Mendeleev's work. Perhaps it can be argued that Mendeleev was in fact a physicist as he himself used the Pauli Exclusion Principle (without knowing it) by noticing the similarities of elements of similar electron configurations, but then we have a scientist who is both physicist and stamp collector, thus disproving Rutherford's original statement.

'All science is either physics or stamp collecting'

Was Rutherford correct in this statement? Can it be that all of science is merely physics, applied physics and collating data?

I think the complexity of the arguments for and against the statement all stem from the simplicity of the statement. I have shown that you can argue that all science stems from the fundamentals of Physics. So, in a way, Rutherford was right to think of Chemistry and Biology (et al.) as subcategories of Physics, rather than 3 distinct subjects under the umbrella subject of science. There is too much overlap and cross over between the subjects to be able to clearly define each science without using the definition of the others. But is it right to think like this? We can rightly (yet simply) say that Chemistry is applied Physics, and Biology is applied Chemistry, but that makes neither subject less important than the Physics that created their fundamentals.

Perhaps even more importantly, it is not correct that Rutherford felt superior to those collecting data and classifying molecules and organisms around him. Scientists at the time of Rutherford and in the developing science of today have shown the importance of classification, for example of particles, in the development and evolution of modern science. Is all science not some form of classification? In science we are seeking to acquire knowledge about the world around us; we are looking to understand completely how the world works, both so our technology can develop but also because of a thirst for knowledge. Rutherford himself, discovered alpha and beta rays and radiation. Did he therefore not classify different types of radiation? And were these classifications not incredibly important to continuing to move science forward?

To quote Isaac Newton **"If I have seen further it is by standing on the shoulders of Giants."** [9] No scientific discovery is isolated from the work of previous scientists. No scientist can claim sole credit for his or her own work. All scientists have and will always rely on the data that proved the theories of the scientists that came before them.

And so, it may be reasonable to describe all science as physics, but this description should not take away the importance and merits of each individual subject. However, classification makes an important contribution to scientific knowledge and should not be dismissed as mere 'stamp collecting'.

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