Teacher notes

Four women in Physics.

It is no secret that Physics has been a male dominated field for ever, intimidating and outright rejecting the entry of women in the field. The one notable exception is the case of the amazing Marie Skłodowska-Curie with her two Nobel prizes, one in Physics and one in Chemistry! But even she, had to face opposition and mistrust: invited to the Royal Institution in London with her husband Pierre Curie, only Pierre was allowed to lecture. The Nobel committee almost removed her as a candidate for the Physics Nobel prize and reinstated her only at the pressure by Pierre Curie. And she was asked not to appear at the ceremony for the Chemistry Nobel prize because of an affair she had, after her husband's death, with a married man, physicist Paul Langevin. Her reply to the Nobel committee was that she would attend and that her work in Chemistry had nothing to do with her personal life, something the committee had no business with.

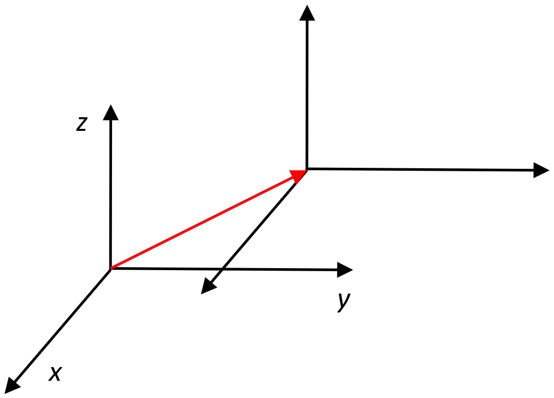
Here are very brief stories about four women in Physics whose work was clearly worthy of a Nobel Prize they never received. They produced superior research despite many obstacles, misogyny and racial prejudice.

Chien-Shiung Wu (1912-1997)

After studying in China, she came to the US for graduate work. Planning to attend the University of Michigan she was shocked to find out that female students were not allowed to enter University buildings through the front door, so she moved to Berkeley instead where she received a Ph.D. under Ernest Lawrence, the inventor of the cyclotron.

Wu is famous for her experiment that showed that parity is violated in weak interactions.

To introduce the idea of parity consider first a co-ordinate system whose origin is translated by some amount giving a new co-ordinate system.

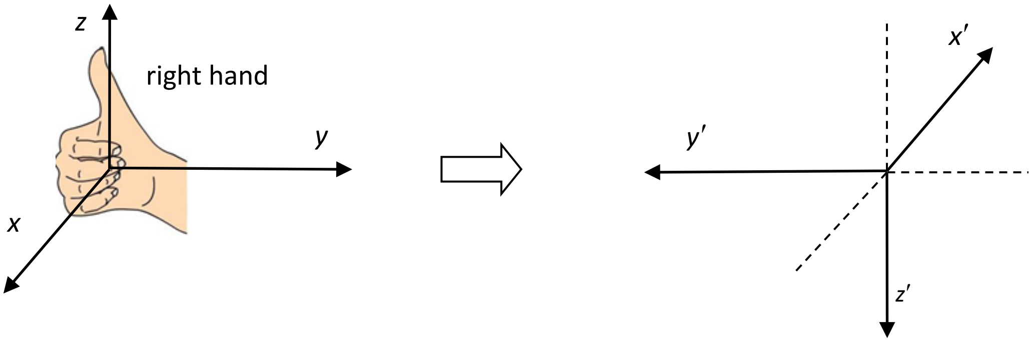


We expect that the laws of physics should be the same expressed in either co-ordinate system. We say that the laws of physics are invariant under a translation of the origin of the axes. Mathematician Emmy Noether showed that whenever the laws of physics are invariant under a continuous operation such as translation, there must be a conserved quantity. In the case of translation invariance, the conserved quantity is linear momentum. We also expect the laws of physics to be invariant under time translation. It should not matter when we start the clock in describing interactions. This leads to energy conservation.

Parity is another symmetry operation. Parity is an operation that reverses the signs of the axes:

$$x \to x' = -x$$
$$y \to y' = -y$$
$$z \to z' = -z$$

A parity operation changes a system into its mirror image. This has the effect of changing the co-ordinate system from a right-handed to a left-handed one. The system on the left is right-handed: when the fingers of the right hand curl from x to y the thumb points in the positive z direction. In the diagram to the right, when the fingers of the **left** hand curl from x' to y', the thumb points in the positive z' axis, a left-handed system.



In the 1950's the laws of physics were thought to be indifferent to whether the co-ordinate system was left- or right-handed. Just as translating the origin of a co-ordinate system by a constant amount had no effect on the laws of physics, reversing the axes was also thought to make no difference. Invariance under this operation would imply a conserved quantity, parity *P*. In any interaction the parity before and after would be the same.

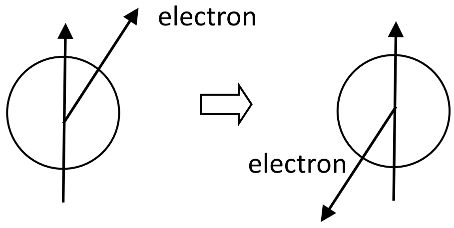
In the 1950's two particles, called Θ^+ and τ^+, were known to decay according to

$$\Theta^+ \to \pi^+ + \pi^0$$
$$\tau^+ \to \pi^+ + \pi^+ + \pi^0$$

Pions, the particles appearing on the right-hand side of the decay equations have parity –1. Because parity is a multiplicative quantum number, the parity of Θ^+ was $(+1)\times(+1) = +1$ and that of the τ^+, $(-1)\times(-1)\times(-1) = -1$. But it soon became apparent that Θ^+ and τ^+ were in fact the same particle, the positive kaon! This created the Θ^+, τ^+ crisis: how could the same particle have different parities?

There was a lot of evidence that parity was conserved in strong and electromagnetic interactions, but the idea had not been tested in weak interactions. T. D. Lee and C. N. Yang proposed that parity might be violated in weak interactions.

This is where Chien-Shiung Wu entered the picture. An expert in beta decay, she undertook the planning and execution of a complicated experiment to test for parity violation in weak interactions. She used the beta minus decay of cobalt-60 nuclei kept at a temperature of 0.01 K (!). The low temperature was necessary so that all cobalt atoms had their spin pointing along the direction of an applied magnetic field. At higher temperatures, thermal motion would destroy this alignment of spins. If parity were conserved equal numbers of electrons would be emitted parallel to the magnetic field as in the opposite direction. But in Wu's experiment more electrons were emitted opposite to the magnetic field indicating a violation of parity. To see why this asymmetry in the emission of electrons implies parity violation consider: under a parity transformation angular momentum and hence spin remains unchanged ($\vec{r}\times\vec{p} \to (-\vec{r})\times(-\vec{p}) = \vec{r}\times\vec{p}$), but the electron velocity changes sign ($\vec{v} \to -\vec{v}$). The following figure shows a cobalt nucleus and its spin (vertical arrow) and an electron emitted in the direction of the spin. The second diagram shows the parity reversed situation.



If parity is not violated, we should not be able to tell the difference between the two diagrams. This happens only if equal numbers of electrons are emitted in the forward and backward direction.

T.D. Lee and C. N. Young received the Nobel Prize in Physics in 1957 for their suggestion that parity might not be conserved in weak interactions. Both had argued for the inclusion of Wu, but the Nobel committee decided not to award the prize to her.

Lise Meitner (1878-1968)

Lise Meitner was the second woman to be awarded a Ph.D. in Physics in Austria. Having been introduced to Max Planck, she accepted his offer to come to Germany where she spent many years as the unpaid assistant to chemist Otto Hahn. On many occasions she proved herself as a very able and imaginative experimentalist who could do independent research on her own. But there was always opposition. In a lecture she gave in Berlin entitled “Cosmic Physics” the press reported it as “Cosmetic Physics”.

In 1939, Hahn and Fritz Strassmann observed nuclear fission: a nucleus of uranium bombarded by a neutron split into two smaller nuclei. By then, Meitner had escaped Nazi Germany and found herself in Sweden with Bohr’s help. Hahn wrote to her of the fission event and Meitner along with her nephew Otto Frisch properly explained what was happening and calculated, and then measured, the amount of energy released, about 200 MeV. This was an event that changed human history as it ushered in the nuclear age.

Strassmann received the Nobel prize in Chemistry in 1944. Despite being nominated many times for the Nobel prize in Physics for her work on fission (by Planck, Heisenberg and Bohr), Meitner never received it.

In the first photograph above, Lise Meitner is in the company of Bohr, Heisenberg, Pauli and Ehrenfest in a lecture in Copenhagen. She is one of just two women in the audience. In the second photograph she is in the lab with Otto Hahn.

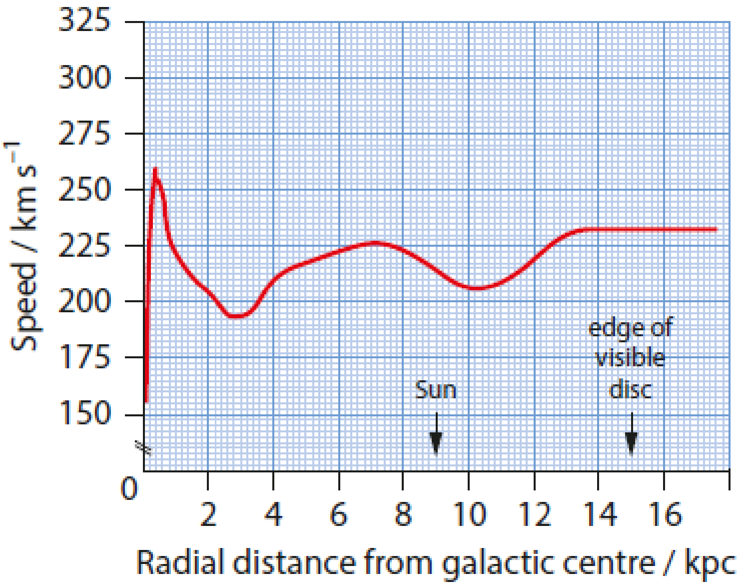
Vera Rubin (1928-2016)

Vera Rubin graduated with full honors from Vassar College in 1948 and was accepted for graduate work at Princeton. But she was not allowed to pursue a Ph.D. in Astronomy as Princeton did not accept women for Astronomy at that time. She finally got a Ph.D. from Georgetown University working under the legendary George Gamow who was then at George Washington University.

Vera's career involved various positions, many times at institutions that had no facilities for women.

The work for which she is mostly remembered and many think was worthy of a Nobel Prize in Physics is her groundbreaking observations of galactic rotation curves.

The graph shows the variation of the rotational speed of stars with distance from the galactic center.



The curve becomes essentially flat as we move far from the galactic center. The graph above is for our own galaxy. It can be shown that the flatness of the curve far from the center is evidence for substantial mass far from the center. However, this mass is not visible, presumably because it does not radiate. We know of its existence through its gravitational effects. This is called dark matter and what it consists of is still uncertain. It is estimated that the dark matter in our galaxy forms a halo around the galaxy and has a mass that is 10 times the mass of the stars in the galaxy. It is estimated that 85% of all the matter in the Universe is dark matter!

For this pioneering work Vera Rubin received many awards but not the Nobel prize. She is considered a pioneer who paved the way for many younger women physicists.

Jocelyn Bell-Burnell (b. 1943)

Jocelyn Bell was a graduate student at Cambridge University working under Anthony Hewish. She helped build a radio telescope to receive radio signals from distant objects. In 1967 she observed a series of pulses received at very regular intervals of time (fractions of a second in her case to tens of milliseconds for pulsars discovered afterwards).

What Jocelyn Bell discovered was a pulsar (actually two of them): a rapidly rotating neutron star with a strong magnetic field that was not aligned with the axis of rotation.

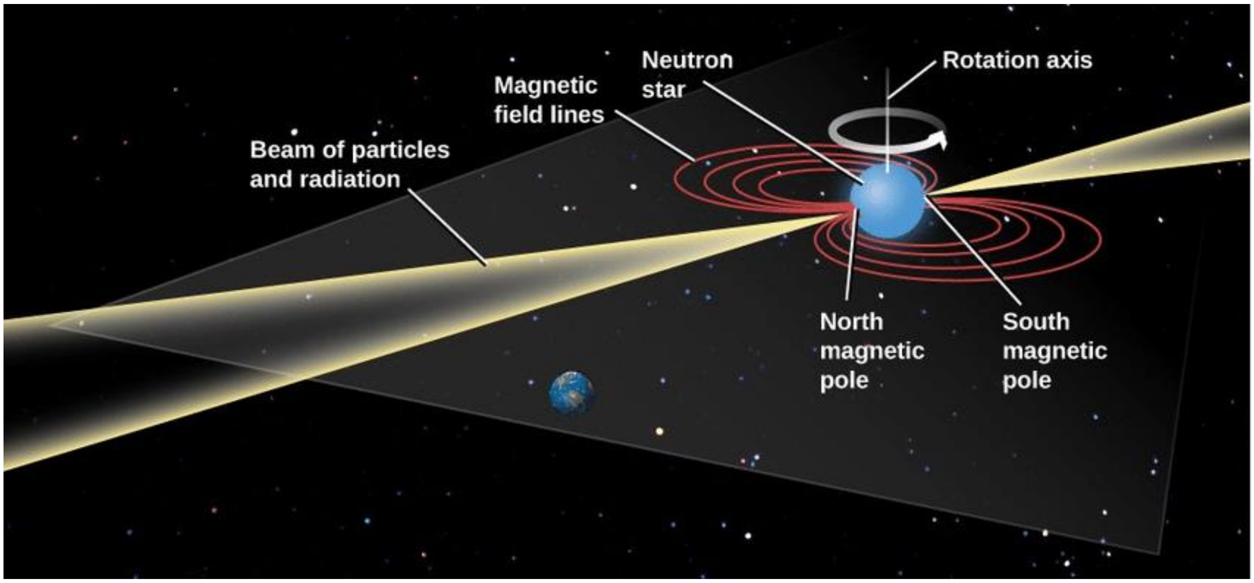


Image due to Paulo Vitor Campos Souza
in https:// courses.lumenlearning.com/astronomy/chapter/pulsars-and-the-discovery-of-neutron-stars/

The star sends out electromagnetic waves in a cone around the direction of the magnetic field axis. As the star rotates, the radiation emitted keeps changing direction much like the searchlight of a lighthouse. Every time the earth finds itself within such a cone, a pulse is registered. This interpretation of what was going on was given by Fred Hoyle the legendary Cambridge astronomer at the end of a colloquium given by Hewish announcing the discovery. It turned out to be correct. The neutron star is formed when a massive star evolves past the main sequence into a red giant or super giant and is the remnant of the star when it explodes as a supernova. It has a radius of a few tens of km and a mass roughly that of the sun.

This was a great discovery that opened new areas of research in Astrophysics and became a testing ground for models of star formation as well as general relativity and gravitational waves.

Her supervisor, Anthony Hewish, and Martin Ryle, the head of the Cambridge radio astronomy group, received the Nobel prize for the discovery of pulsars in 1974. Jocelyn Bell was excluded. In a 1977 interview Jocelyn Bell said that she was not upset about this decision and that it was a fair and right decision. Not everyone agreed, including Hoyle who publicly supported her inclusion in the prize. But see https://www.youtube.com/watch?v=NDW9zKqvPJI where it appears she had a changed view on the matter.