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CHRONOLOGICAL GLOSSARY

Names of major contributors to physics, chemistry, and astrophysics, following the thread of The Magic Furnace, by Marcus Chown

Please note: This chronological version has the same content as the alphabetic one, except that under certain names I have added some commentary below a dotted line.

1. Anaxagoras 500 BC - 428 BC
Greek philosopher who proclaimed that the sun is a hot, glowing ball of iron not much bigger than Greece.

2. Democritus 470 BC
He was the first to come up with idea that all matter is composed of atoms (meaning they cannot be split, often referred to as "elementary" in today's lingo). He reasoned that water is atoms plus void, otherwise fish could not swim through it, nor could salt dissolve in it. His conclusion, "In reality, there are only atoms and the void."

3. Copernicus, Nicolaus 1473 - 1543
Polish Monk, one of the greatest of the renaissance polymaths, and the first person to formulate a comprehensive heliocentric cosmology. Copernicus, living before the invention of the telescope, reasoned that absence of parallax (that could be measured then) implied the stars were very distant. From this he came up with a far simpler paradigm than that of Ptolemy.

4. Brahe, Tycho 1546 - 1601
Danish astronomer who proved that the Church's "heavenly spheres" are not immutable, that comets, supernovae (SN 1572), etc. lie outside them.

5. Bruno, Giordano 1548 - 1600

Italian friar, philosopher, mathematician, and astronomer. Rapidly oxidized by the Church for advocating the idea that sun is a nearby star, and that the universe has an infinite number of worlds inhabited by intelligent beings.

6. Newton, Isaac 1614 - 1727
English physicist, one of two mathematicians to independently invent calculus, and one of the foremost intellects of all time. Newton achieved the first great unification in physics by identifying earthly gravity with the force acting on celestial bodies. He confirmed the Galilean idea that a body's motion persists until a net force acts on it, and he extended this idea to F = MA, and the law of action and reaction. His work with telescopes, including his invention of the reflector telescope, and on the spectrum of light, laid groundwork for all future astronomy and optics. He was the first person to raise the question, What powers the sun?

7. Hauksbee, Francis 1666 - 1713
English physicist who in 1709 invented a discharge tube that would later be engineered into the neon light. He isolated “electricity”, which was previously encountered in, and confused with the properties of, a copper wire, by placing electrodes in a blown glass tube with reduced air or gas pressure. Voltage on the electrodes produced sparks zig zagging between them. See Plucker and Hittorf, who picked up this thread much later.

8. Bernoulli, Daniel 1700 - 1782
Dutch-Swiss mathematician from a prominent family of mathematicians, best known for Bernoulli's Law of fluid mechanics, which explains how airplanes fly. He applied Newton's First Laws to the concept of atoms (actually molecules) in a gas: When in motion a body tends to stay in motion. Thus the atoms in a gas will travel in straight lines until they collide with one another or with the walls of their container. From this, and the assumption that collisions are elastic, he predicted the three gas laws later known as Boyle's, Charles', and Gay Lussac's, which combine into the perfect gas law, PV = NRT. Was way ahead of his time.

Bernoulli is also known for his work in mathematics and statistics.

9. Lavoisier, Antoine 1743 - 1794
French chemist. In 1789 he compiled a list of 23 elements as a basis for all

compounds, a list which rapidly grew as more workers identified more elements. He also discovered the rule of conservation of mass in chemical reactions. A well connected aristocrat living at the time of the French Revolution, Lavoisier was guillotined in 1794.

10. Dalton, John 1766 - 1844
English chemist, physicist, and meteorologist. In 1803, he noticed that elements always combined in fixed proportions by weight, and saw this as evidence that atoms were combining in fixed number ratios, now known as stoichiometric ratios. The "Dalton", one unit of chemical mass, is now defined as 1/12 of the mass of the atomic and nuclear ground state of the common isotope C-12.
Five main points of Dalton's atomic theory (obviously dated in the light of today's knowledge)

1. Elements are made of extremely small particles called atoms.
2. Atoms of a given element are identical in size, mass, and other properties;
3. Atoms cannot be subdivided, created, or destroyed.
4. Atoms of different elements combine in simple whole-number ratios to form chemical compounds.
5. In chemical reactions, atoms are combined, separated, or rearranged.

11. Young, Thomas 1773 - 1829
English polymath and physicist who discovered the wave nature of light, and measured its wavelength. This allowed Fraunhofer to pin down the precise wavelengths of the spectral lines he was observing in the sun and bright stars.

Wikipedia: He is famous for having partly deciphered Egyptian hieroglyphics (specifically the Rosetta Stone) before Jean-François Champollion eventually expanded on his work. He was admired by, among others, Herschel and Einstein.

12. Ampere, Andre-Marie 1775 - 1836
French mathematician and physicist, known best for his work on electricity, and for Ampere's Circuit Law. He found in 1814 that atoms of one element in a gas

usually combine into diatoms (molecules with two atoms such as H_2, N_2 , and O_2). This allows weight comparisons of molecular gasses to imply atomic weights.

13. Prout, William, 1785 - 1850
English chemist, physicist, and natural theologian, he is remembered today mainly for what is called Prout's hypothesis.

Using the results of Ampere and others, he stumbled upon the remarkable discovery that all the atomic weights he measured are near multiples of the weight of hydrogen. Based on this, he theorized that all elements were composites of hydrogen. Not quite right, but on the right track, and useful as a standard of comparison for others.

It's well to remember that this was before the basic structure of the atom was understood. Today, we have the Rutherford model of the atom, we know that the nucleus is composed of protons and neutrons, and we know that atomic weight is not just a linear sum of the weights of the bare neutron (N), the bare proton (P), and the elections.

Binding energy is the negative energy that holds some things together, like the energy you would need to escape the earth's gravitational field. As a rule, and for elements with atomic number less than iron (Fe), when lighter nuclei fuse into a heavier one, they form a bound state of lower mass-energy (higher binding energy) due to the attractive nuclear force that holds them locked together despite the powerful repulsive electrical force acting between every pair of protons. The greater the "binding energy", the more stable the nucleus against radioactive decay. The helium nucleus, known as the alpha particle, consists of two protons and two neutrons, and is the prototype of a stable isotope. Its large binding energy allows it to be an integral particle of radioactive decay. Thus, alpha radioactivity.

For elements with more protons than Fe has, binding energy decreases as one climbs up the ladder of the elements, and so it is fission, not fusion, that releases energy.

14. Avagadro, Amedeo 1776 - 1856
Italian lawyer turned physicist who, in 1811 published Avagadro's Law: that a fixed volume of gas at STP has a fixed number of molecules independent of the chemical ID of the gas. A volume of 22.4 liters at STP has what is defined as one mole of gas. One mole = 6.0221415×10^{23}. His law allowed others to compare the atomic weights of the various molecular and atomic gasses, without knowing the atomic makeup of the gas molecule in question.

15. Von Fraunhofer, Joseph 1787 - 1826
German physicist who discovered the sharp, dark absorption lines in the spectrum of the sun, and a few bright stars. Further work later revealed about 25,000 of them. See Bunsen. He and a co-worker also did a lot of work on elemental abundances in stars, later used in B^2FH.

16. Herschel, John 1792 - 1871
English mathematician, chemist, and astronomer well known for his observations in the southern hemisphere. He measured the heat output from the sun, which emphasized the question, What powers the sun?

17. Plucker, Julius 1801 - 1868
German mathematician and physicist. In 1858 he continued Hauksbee's early work, using more highly rarified gasses. At lower gas density, Hauksbee's jagged lightning bolts became a continuous glow. Further pumping down of the gas pressure resulted in blackness, with only a faint glow near the termination of the ray at the end of the glass tube.

18. Angstrom, Anders 1814 - 1874
Swedish physicist whose name defines the atomic scale distance, one Angstrom, which is 10^{-10} m. He showed that a spectral line is in emission or in absorption relative to the adjacent continuum radiation of a background source depending on whether the line is formed in a gas which is hotter or cooler than the background source. One major consequence of this is that the relatively cool outer layers of a star produce absorption lines on the background continuum of black body

radiation propagating up from the deeper and hotter layers of the star. Solar prominences rising above the photosphere, and seen against the background of space, will exhibit lines in emission.

19. de Marignac, Jean-Charles 1817 - 1894
Swiss chemist who, in 1861, published a paper claiming that his mass deficit measurements proved Prout's rule to be inexact: that all elements are composites of hydrogen. He was ahead of his time when he attributed this mass deficit to lost energy, thereby predicting the equivalence of mass and energy, beating Einstein to the punch by 44 years. But, it was Einstein who derived the quantitative relation $E = Mc^2$.

20. Hittorf, Johann 1824 - 1914
German physicist, student of Plucker. Applying the laws of EM, he used magnets to deflect the ray in a discharge tube, showing it to be electrically charged. He created shadows of objects in its path to confirm it was traveling in straight lines. These results opened the path to a major discovery by J.J. Thompson.

21. Thomson, William (Lord Kelvin) 1824 - 1907
Most honored British scientist of all time. He devised the Kelvin temperature scale which we use universally in all physical science, discovered the first and second laws of thermodynamics, and wrote some 600 papers over a broad range of topics. He advocated Helmholtz' early and incorrect idea that the sun is powered by gravitational contraction which has been reducing it from a larger nebula for some 30 MY.

22. Huggins, William 1824 - 1910
Wealthy English amateur astronomer who spent his life laboriously recording the line spectra of hundreds of stars, repeatedly encountering the laboratory line spectra reported by Bunsen. The combined work of Kirchoff and Huggins made it clear that the stars were made of the same chemical elements as found on the earth, but the relative abundances in stars were still unknown.

23. Kirchoff, Gustav 1824 - 1887
German physicist well known for his work on electric circuits, spectroscopy, and

black body radiation, which he named. He suggested to Bunsen that a prism should replace Bunsen's awkward use of glass light filters to determine the precise wavelengths of spectral lines. This led to a collaboration that revealed that Bunsen's emissive flame spectra was identical to Fraunhofer's absorption spectra in the sun, and stars. The important implication of this is that the sun and stars are composed of the same chemical elements as those found in the earth. He reasoned from the work of Angstrom that the sodium lines in the sun were in absorption because they were formed in the cool outer layers of the sun's atmosphere, illuminated by the hotter layers below.

This insight lies at the foundation of radiative transfer in stellar atmospheres, the science by which astronomers calculate chemical abundances from the widths and depths of spectral lines, and determine the run of temperature in the region of line formation. Radiative transfer in spectral lines is also used to model the radiative driving forces that drive stellar winds, some of which carry off enough mass (25%) to alter the evolutionary course of the star.

24. Balmer, Jacob 1825 - 1898

Swiss mathematician and physicist best known for discovering empirical formula for the wavelengths of the hydrogen in the visible spectrum, now known as the Balmer series. Balmer's formula (for n_1=2) was later found to be a special case of the Rydberg formula, devised by Johannes Rydberg.

$$\frac{1}{\lambda} = \frac{4}{h}\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right) = R_H\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$$

25. Maxwell, James Clerk 1831 - 1879

Scottish mathematician and physicist who unified electricity and magnetism in four linear, differential equations know as Maxwell's Equations. This was the second greatest unification in physics, the first being that of Newton, who identified earth's gravity with the force acting on celestial bodies.

Maxwell also helped develop the Maxwell-Boltzmann distribution, the statistical spread of velocities found in every gas in thermal equilibrium.

Maxwell's Equations, based on previous lab work by Ampere, Faraday, and others, connect the spatial gradients and time derivatives of the electric field E and magnetic field B. Two of these four linear equations, when set in a vacuum with no sources or sinks, were found by Maxwell to yield a traveling wave solution with speed "c" of propagation a constant, as observed in all moving reference frames. Einstein showed that this anti-intuitive but stubborn fact implies that measurements of length, mass, and time for material objects become highly skewed at velocities in the range of c, and that no massive object can be measured to move faster than c. The theory of special relativity (not called that by him) was published in his famous paper of 1905. The most well known result of SR is $E = mc^2$.

SR was the salvation of those perplexed by the breakdown of Prout's hypothesis. As Aston perceived, the anomalous low atomic weight (mass) of all isotopes relative to hydrogen represents a state of lower total energy through $E = mc^2$. When binding energy is expressed as binding energy per nucleon, and it is plotted against atomic number, the result is called the curve of binding energy. This curve serves as a model for understanding the energetics of all nuclear transmutations: radioactivity, fission and fusion reactors and weapons, and nuclear reactions in stars and supernovae. Being a very difficult problem in computational quantum physics, nuclear mass-energies are usually measured experimentally.

26. Mendeleev, Dimitri 1834 - 1907
Siberian chemist who discovered repeating properties in the 67 elements known in his time, from which he organized them into his well known Periodic Table of the Elements. Many as yet undiscovered elements were found as missing entries in his table. His work was empirical. Understanding chemical properties in terms of electron shells, valences, and the Exclusion Principle, would have to come later.

27. Comte, Auguste c 1835
French philosopher who asserted that the chemical composition of the stars will never be known because we cannot travel to the stars.

28. Lockyer, Norman 1836 - 1920
English amateur astronomer with a keen interest in spectroscopy who, with Pierre Janssen, discovered helium in the limb (edge) of the sun, and named helium after the sun.

29. Chamberlain, Thomas 1843 - 1928
American geologist who anticipated a radioactively self-heated earth, discovered CO2 in the earth's atmosphere, started the concept of climate change, and, based on his knowledge of geologic time scales, challenged Lord Kelvin's gravitational contraction theory for the energy output and age of the sun, 30 MY. Geologists and Darwinian biologists of that day, not yet enlightened by radio dating, were estimating 100 MY.

30. Röentgen, Wilhelm Conrad 1845 - 1923
Wikipedia: German physicist, who, in 1895, produced and detected electromagnetic radiation in a wavelength range today known as X-rays or Röntgen rays, an achievement that earned him the first Nobel Prize in Physics in 1901.

31. Becquerel, Henri 1852 - 1908
French minerologist and physicist. In 1896, while studying phosphorescence in uranium salts, a non-nuclear phenomenon, he discovered nuclear radioactivity by accident and hunch.

32. Thompson, Joseph, John "JJ" 1856 - 1940
British physicist credited with the discovery of the electron, and of isotopes. In 1897, working with discharge tubes, he used opposing and balanced forces from magnetic and electric fields to determine the charge and mass of the electron. The first sub-atomic particle had been found. The electron was found to be about 1/2,000 the mass of the hydrogen atom, later found to be about 1/1836.

The mysterious tube discharge was now seen as very light negatively charged particles (electrons) ripped off metal electrodes and accelerated across the tube by the applied electric field, and subject to magnetic fields which can be used to deflect them. Using the ability to discriminate on the basis of a particle's charge-to-mass ratio, Thompson pioneered the mass spectrograph, which is used to physically separate the isotopes of an element in an ionized beam.

33. Curie, Marie 1867 - 1934
French chemist born in Poland, often called "the greatest woman scientist". Working with husband Pierre Curie, in 1898, she discovered radium and polonium in pitchblende ore through their anomalous high radioactivity. They isolated and worked extensively with radium, revealing the enormous store of energy latent in this isotope, and by implication, in the nuclei of other elements. After working to find therapeutic uses of radium, she died of cancer, probably due to her high exposure to this dangerous element.

All isotopes of radium are highly radioactive, the longest of their half-lives being 1601 years. Radium decays into radon gas, also radioactive, a concern to many in Colorado because radon is also a decay product of uranium and thorium, which are present in our rock. The most stable isotope of radon is Rn-222; it has a half life of 3.8 days.

34. Perrin, Jean Baptiste 1870 - 1942
French physicist. Using lab data and Einstein's quantitative theory for Brownian motion he calculated the size of water molecules, about 10^{-10} m, or one Angstrom. This was the first time the size of an atom or molecule had been calculated.

He also suggested that the sun is powered by some sort of sub-atomic energy released in the conversion of H to He.

35. Rutherford, Ernest 1871 - 1937
British physicist born in New Zealand, the "father of nuclear physics".
In 1899, soon after Becquerel discovered radioactivity and Roengten produced X-rays, he identified alpha and beta rays in natural radioactivity, and some of their properties. He discovered the tiny size and strong electrical repulsion of the atomic nucleus by suggesting that Marsden and Geiger, who were exposing a thin sheet of gold foil to alpha particles, look for alphas bouncing back at large deflection angles. When they revised their detector, they found that most of the

alphas missed their heavy target nuclei in the foil, but one out of about 8,000 hit and bounced back at wide angles, indicating the tiny size and large electrical repulsion at close range of the positively charged, heavy atomic nucleus of gold. In earlier work he showed that radioactivity involves nuclear transmutation: He transformed nitrogen-14 into oxygen-17, by bombardment with alpha rays, discovering that the proton can be spit out as a particle of radioactivity. He had performed the first act of artificial nuclear alchemy. He discovered and named half-life, and worked on the application of half lives to geologic dating, concluding that the age of the earth is 4.6 BY.

36. Soddy, Frederick 1877 - 1956
Wikipedia: English radiochemist who explained, with Ernest Rutherford, that radioactivity is due to the transmutation of elements, now known to involve nuclear reactions. He also proved the existence of isotopes of certain radioactive elements. He received the Nobel Prize for Chemistry in 1921, and has a crater named for him on the far side of the Moon.

37. Aston, Francis 1877 - 1945
British chemist and physicist. Started as assistant to JJ Thompson in 1910. In 1919 he built the first full, functional mass spectrometer. He discovered isotopes, and thereby explained non-integral atomic weights as isotopic mixtures. This resolved the problem of an element that strongly violated Prout's hypothesis, namely chlorine. But, in 1919 he also found that relative to oxygen, and other elements, hydrogen has too much mass (1.008 x 1/16 of oxygen). Ultimately, this led to the modern theory of nuclear binding energy, which underpins all nuclear applications, including medical isotopes.

Wikipedia:
After the war he returned to research at the Cavendish Laboratory in Cambridge, and completed building his first mass spectrograph that he reported on 1919. Subsequent improvements in the instrument led to the development of a second and third instrument of improved mass resolving power and mass accuracy. These instruments employing electromagnetic focusing allowed him to identify 212 naturally occurring isotopes. In 1921, Aston became a fellow of the Royal Society and received the Nobel Prize in Chemistry the following year.

His work on isotopes also led to his formulation of the whole number rule which states that "the mass of the oxygen isotope being defined [as 16], all the other isotopes have masses that are very nearly whole numbers," a rule that was used extensively in the development of nuclear energy. The exact mass of many isotopes was measured, leading to the result that hydrogen has a 1% higher mass than expected from the average mass of the other elements. In 1936, Aston speculated about subatomic energy and its possible use.

38. Russell, Henry Norris 1877 - 1957
American astronomer who, with Hertzsprung, introduced the Hertzsprung-Russell (H-R) Diagram, which allows a scatter plot of the stars over luminosity and surface temperature, and a convenient way of tracking their evolution. Russell extensively studied red giants and catalogued their surface temperatures.

39. Einstein, Albert 1879 - 1955
Wikipedia: German-born theoretical physicist who developed the theory of general relativity, effecting a revolution in physics. For this achievement, Einstein is often regarded as the father of modern physics and one of the most prolific intellects in human history. He received the 1921 Nobel Prize in Physics "for his services to theoretical physics, and especially for his discovery of the law of the photoelectric effect".[4] The latter was pivotal in establishing quantum theory within physics.

For the thread of this glossary, Einstein is most important for establishing the equivalence of mass and energy, $E = Mc^2$, which is a basic principle underlying the transmutation of the elements, and the luminosity of the stars.

He also confirmed the atomic hypothesis through his explanation of Brownian motion in pollen grains floating on water. But, he did more than explain. He built a quantitative theory which led to the first determination of the size of atoms.

Along with his brilliant originality, Einstein refused to accept new discoveries in quantum mechanics and astrophysics which conflicted with his religious world view, and, rather than join those in the advancing research on quantum mechanical atomic and nuclear physics, he spent the last decades of his life pursuing a classical unified field theory of gravitation and EM that went nowhere.

40. Eddington, Sir Arthur 1882 - 1934
English astrophysicist who did structure calculations of stars, starting with the easy case of red giants (with their cool cores). These pioneering computations improved on previous work by Martin Schwartzchild with the inclusion of radiation as the dominant store of energy relative to the heat energy of the plasma, but assumed incorrectly that atoms in the stellar regime are not ionized. Much of the pressure to support a star against its own gravity comes from the electrons liberated by ionization.

In the 1920s, he introduced the idea that proton–proton reactions were the basic principle by which the Sun and other low mass stars fuse hydrogen into helium, releasing binding energy in the process. Working without knowledge of nuclear tunneling he concluded that his stellar core temperatures would not sustain a P-P reaction.

Eddington is also known for his expedition of 1919 to observe an eclipse of the sun and the angle deflection of star images near the occulted solar disk due to gravitational curvature of space and time. This resulted in a rough quantitative confirmation of general relativity.

Though a pioneer in stellar structure Eddington never accepted, and heavily ridiculed, the new idea originating with S. Chandrasekhar, that white dwarf stars can collapse into nuclear density "neutron stars" when their mass reaches the Chandrasekhar Limit, 1.4 times the mass of the sun.

41. Bohr, Niels 1885 - 1962
Danish physicist who postulated quantized electron orbits to explain the Balmer series of spectral lines in hydrogen spectra. The Bohr Atom has orbits quantized by an integral number of de Broglie waves fitting around the orbit. The correct orbits, now found in every high school chemistry text, are spatially fuzzy orbitals calculated from Schrodinger's equation. Bohr was a key advocate of quantum theory, and argued extensively with Einstein, who felt strongly that his "God" would never allow nature to be fundamentally probabilistic. Einstein was convinced that quantum theory would some day be replaced by a non-probabilistic theory.

42. Friedmann, Aleksandr 1888-1925
Russian cosmologist who pioneered the use of Einstein's general theory to model the geometry of the universe. He advocated the Big Bang idea seven years before Hubble found evidence for an expanding universe. He is known for the Friedmann Equation, an energy conservation equation whose solution is the time dependent rate of expansion of space-time. He categorized cosmological models into those with space which is positively or negatively curved, or flat. Universes with positive curvature are closed and eventually collapse. Those with negative curvature are open and expand forever. The flat ones lie on the mathematical borderline.

43. Chadwick, James 1891 - 1974
English physicist who discovered the neutron. Wikipedia: In 1932, James Chadwick proved that the atomic nucleus contained a neutral particle which had been proposed and named more than a decade earlier by Ernest Rutherford. His experiment found the neutron to be about 0.1% more massive than the proton.

Two more years were required to learn that the neutron is not a composite of a proton and an electron. We know today that it, like the proton, is composed of three inextricable quarks, and that at least 98% of its mass-energy, and that of the proton, is in the form of massless bosons called gluons. The neutron is slightly more massive than the proton (0.01%). When isolated outside the nucleus, it decays in about 15 minutes via the weak interaction into a proton, an electron, and a neutrino.

44. Saha, Meghnad 1893 - 1956
Indian physicist who combined Bohr's theory of the quantized atom with thermodynamics to derive the Saha formula for the relative number densities of the ionization stages of an atom. This is important to spectral analysis and structure computations in astrophysics, as several different stages of ionization might be simultaneously present in various regimes of temperature and density in the deep interior, or in the line forming atmosphere of a star. The Saha Equation, used together with Boltzmann's Equation, can determine the populations (particles per cubic centimeter) of every atomic excitation level of every ion stage of every

element in a gas or plasma in local thermodynamic equilibrium (LTE) with a known temperature and density at the point in question.

Non-LTE plasmas or gasses are those in which some of the populations are partially controlled by radiation not emitted by local thermal processes. An extreme example would be the multiple scattering of Lyman alpha resonance line radiation in the galactic halo.

45. Baade, Walter 1893 - 1960
German-American astronomer who recalculated and thereby doubled the size of the universe, who identified two distinct types of Cepheid variables, who identified two stellar population types based partly on chemical abundances, and who identified supernovae as a new category of astronomical object.

46. Urey, Harold 1893 - 1931
In 1932, he discovered the hydrogen isotope deuterium (one neutron and one proton locked together by the attractive strong force), an intermediate step in building He from H in the proton-proton chain in stars like the sun that are too cool for Bethe's carbon cycle to operate efficiently.

47. Atkinson, Robert 1898 - 1982, and **Houtermans**, Fritz 1903, 1966.
English experimentalist, and German theoretician, grouped together here due to their fruitful collaboration. Both worked with Gamow on alpha emission via quantum tunneling. Then, in 1919, after reading Eddington's book, Internal Constitution of the Stars, Atkinson informed Houtermans of the problem of nuclear burning at the relatively low temperatures in the cores of stars that Eddington had newly calculated. Houtermans then came up with the idea that quantum tunneling might allow nuclear fusion of hydrogen into helium in the sun at these low core temperatures. This was done with no knowledge of nuclear physics, and therefore it did not include the essential transformation of a proton into a neutron in the brief instant of the collision of two protons. For this, it was necessary to understand the weak force.

Houtermans led a dramatic and colorful life, skating on thin political ice, and getting bailed out of predicaments by influential friends.

48. Payne-Gaposhkin, Cecilia 1900 - 1979
English astronomer who, when disallowed, due to her gender, from an academic program in England, went to Radcliff and proceeded to make a major breakthrough. First, she studied the spectra of many stars in the Harvard catalogue, attempting to determine chemical abundances. In 1925, after learning of Saha's method to determine per-cent neutral hydrogen in the sun, she did so and found that almost all the hydrogen in the sun's photosphere is ionized. She concluded, hesitantly, from this and the strong hydrogen absorption lines in the solar spectrum, that the sun must be composed mainly of hydrogen, but also helium, the other elements being present in trace abundances. This finally killed the idea which started with Anaxagores in pre-socratic Greece, that the sun is a hot glowing ball of iron. One implication of Cecilia Payne's basic finding is that the sun has enough hydrogen fuel to burn (into helium) for many BY.

49. Gamow, George 1904 - 1968
Russian born physicist, cosmologist, and science writer. He conjectured the original explosive expansion of the universe, derisively named the "Big Bang" by Fred Hoyle. Early in his career he solved the mystery mechanism for alpha radioactivity: quantum tunneling through the potential force barrier of the strong force. Working with his student Alpher, he pursued the rational but incorrect idea that all the elements, in their modern proportions, were forged in the Big Bang, all in one furnace. From the Big Bang model Alpher predicted the three degree cosmic background radiation, now considered perhaps the most fertile area of research into cosmology. Gamow suggested that the sun produces its luminous energy by fusing H into He, but failed to see that quantum tunneling can work to facilitate fusion as well as fission, which solves the mystery of how H to He fusion events can occur at Eddington's relatively cool temperatures in the cores of low mass stars. Highly creative and imaginative, Gamow wrote the popular books: "Creation of the Universe", "Birth and Death of the Sun", and "One Two Three Infinity". His last years were spent here at the CU Physics Department. He is buried in the Columbia Cemetery, in Boulder.

50. Bethe, Hans 1906 - 2005
German-American theoretical nuclear physicist. Worked in several areas of physics, especially the theory of beta radioactivity, the most common action of the weak force. In 1934, he discovered the carbon cycle, a catalytic mechanism

involving C, N, and O, for fusion of H into He in stars with hotter cores than has the sun. He found the temperature dependence of the carbon cycle reaction rate to be T^{17}. This extreme sensitivity to temperature is due to the temperature sensitivity of the high energy tail of the thermal velocity distribution, and the sensitivity of quantum tunneling probability to collision velocity. The carbon cycle was independently discovered at the same time by Carl Von Wiezsacker.

In the P-P reaction Bethe found that one of the protons could decay into a neutron in the brief instant of fusion, transforming the highly tenuous PP pair into NP, which is the stable hydrogen isotope, deuterium. Deuterium then absorbs another proton, becoming He-3. Two He-3 nuclei can then combine into one He-4 plus two free protons. This is the proton-proton chain that transforms H into He in stars with less mass than 1.5 times the mass of the sun.

It is clear that deuterium abundance in the universe cannot be created by the above process because it is used up as soon as it forms. The trace amount of deuterium in the world today, one deuteron per 6,400 protons, comes from the helium formation era of the hot Big Bang.

51. Fowler, William (Willi) 1911 - 1995
American nuclear experimentalist at Cal Tech who started a program to study the nuclear reactions in the carbon cycle. He correctly concluded that this catalytic mechanism cannot work in the sun due to the relatively low temperature in the sun's core. He later worked with Hoyle and the Burbidges, and is the "F" in the famous paper B-squared FH, which explained the nucleogenesis of all the elements except the lightest ones.

52. Schwartzchild, Martin 1912 - 1997
German-American astrophysicist, son of Karl Schwartzchild known for the Schwartzchild metric of general relativity from which we have the concept of the event horizon of a black hole. Martin Schwartzchild did early computer models of stellar structure and evolution, and applied his numerical techniques to problems like differential rotation (e.g. as seen in the sun) and pulsation (e.g. in Cepheid variables). He is known for his book, The Structure and Evolution of the Stars. Encouraged by Lyman Spitzer, a leader in infrared astronomy, he

pioneered the use of balloons to send IR detectors above the earth's atmosphere.

The use of balloons, rockets, and satellites to loft IR and UV detectors above the atmosphere opened two new fields of astronomy. The earth's atmosphere is opaque in most bands of the IR, and totally opaque to UV. Yet, many spectral lines from ionized species like He+ and C++, are in the UV band. And, many objects of interest, like protostars, or high-Z galaxies, emit most of their luminosity in the IR. These days, IR is becoming increasingly important as we look back into the red-shifted early universe. In two years we hope to see the James Webb Space Telescope launched; IR observations will be its primary mission.

53. von Weizsäcker, Carl Friedrich Freiherr 1912 – 2007
Wikipedia: German physicist and philosopher. He did extensive research in nuclear physics, and discovered the carbon cycle independently of Bethe. He shot down the notion that all the elements could have been forged in one nuclear furnace by showing that each element had to be created at its own temperature and density. This led to the idea that only in the internal conditions of stars could the full range of conditions be found. This idea turned out to be right for all elements but He, Li, Be, and B. Almost all He and Li in today's universe was formed in the Big Bang, while Be and B are thought to be fragments of heavier cosmic ray particles which underwent collisions. This is the X-process in Hoyle's list.

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von Weizsäcker was the longest-living member of the research team which performed nuclear research in Germany during the Second World War, under Werner Heisenberg's leadership. There is ongoing debate as to whether he, and the other members of the team, actually willingly pursued the development of a nuclear bomb for Germany during this time.

54. Hoyle, Fred 1915 - 2001
British nuclear physicist and astrophysicist. Pioneer of stellar nucleosynthesis, and advocate of the "steady state hypothesis" in cosmology. With Fowler and the Burbidges he published a lengthy paper (B^2FH) explaining how all the elements aside from helium and the other lightest elements are forged in stars and

supernovae. This is the most well known paper in astrophysics. It details seven of the eight processes by which the nuclei of the Periodic Table are forged, starting from an early universe of protons and neutrons.

1) P-P chain
2) CNO
3) triple-alpha
4) S-process
5) R-process
6) P-process
7) Hot Big Bang
8) X-process

Hoyle and English physicist Raymond Lyttleton combined their knowledge of nuclear physics, thermodynamics, and stellar astrophysics to construct a model of stellar evolution in which common stars like the sun "burn" H into He, building a He core of nuclear ash which contracts under self-gravitation and thereby liberates heat to the outer layers, which respond by burning H at a ferocious rate. The trapped energy heats the star, which expands into a highly luminous "red giant". The word "red" indicates low surface temperature, and "giant" means that the outer layers expand out to the size of our inner solar system (the sun will do this in about five BY). Hoyle calculated the temperature of the contracted helium core of such a star and found it to be about 100 M degrees, hot enough to fuse helium into carbon by way of the two-step "triple alpha" process. He predicted an excited energy level of the nucleus C-12 based on the fact that the elements heavier than He-4 exists, that we exist. Be-8 is in equilibrium with He-4, having a relative population of about one in a billion. But, during its 10^{-17} second lifetime a Be-8 nucleus is hit by a He-4 about ten thousand times. If C-12 had an excited resonance state at the right energy some of these collisions would be successful at creating a C-12 nucleus, and enough C-12 would be created to explain its abundance in our present universe. At Hoyle's insistence, this anthropic prediction was tested in the lab by Fowler, and on paper by theoreticians, who had previously overlooked it.

By the end of their work on nucleosynthesis Hoyle and collaborators had found, or identified from the work of others, seven processes by which all the nuclei are created. The unknown eighth (X) process is for the creation of Be and B, which are destroyed, not created, in the stellar context. It was later found that these elements are likely to be the remnants of cosmic ray nuclei from supernovae, reduced to Be and B by collisions along their flight path.

In the 1960s, Hoyle addressed the He problem, redoing, with Fowler and Wagoner (Roger) the rough calculations of Gamow et al. They confirmed the idea that He was formed in the Big Bang. How that sat with Hoyle's preference for the Steady State Hypothesis I do not know.

Hoyle's steady state hypothesis denies the Big Bang (Hoyle's term) and states that the universe is unchanging while still expanding. The voids created by this process are filled in by newly created material, from what is sometimes called "white holes". This idea took a big hit when the three degree microwave background was discovered (see Penzias and Wilson in Wikipedia) and found to follow the black body curve, as predicted by Alpher and Herman from Big Bang theory. Today "steady state" is no longer a viable hypothesis.

55. Alpher, Ralph 1921 - 2007, and **Herman**, Robert c 1948
American students of Gamow who carried out calculations that estimated the quantities of elements forged in the first five minutes in the life of the universe. They found, contrary to Gamow's inspiration, that only helium is created under these conditions, plus a tiny trace of lithium. Heavier nuclei could not be forged in the limited time scale of five minutes due to the absence of stable nuclei with 5 or 8 nucleons (protons or neutrons) to bridge the gap to carbon. This finding shot down the hope that the Big Bang was a unique magic furnace where all the elements were made.

Alpher also predicted the three degree microwave background, now the most fertile area of research into the early universe and cosmology in general.

56. Cameron, Alistair 1925 - 2005
Canadian nuclear physicist who discovered the source of neutrons for building heavy elements in stars with less than eight masses. It is the rare isotope C-13, a

by product of the carbon cycle (see Bethe). C-13 combines with an alpha to produce O-16 and a free neutron. For stars with more than eight solar masses he discovered another neutron source, namely Ne-22 combining with an alpha to produce Mg-25 and a free neutron.

57. Burbidge, Geoffrey 1925 - 2010
English-American astronomer. Wikipedia: In 1957 he and his wife were co-authors, together with William Fowler, the American physicist, and Fred Hoyle, the British astronomer, of a famous paper on stellar nucleosynthesis, which was referred to as the B^2FH paper, after the initials of the surnames of the four authors. This paper described the process of stars burning lighter elements into successively heavier atoms which were then expelled to form other structures in the universe, including planets.

In recent years Burbidge was known mostly for his alternative cosmology "quasi-steady state theory", which contradicts the Big Bang theory.

According to Burbidge, the universe is oscillatory and as such expands and contracts periodically over infinite time. This theory, due to its controversial nature, has brought a certain amount of fame (or even infamy) to Burbidge.

B^2FH paper: By Burbidge, Burbidge, Fowler, and Hoyle, maps out the processes by which all the elements are created in stars, except He, Li, Be, and B. It reveals that a sequence of hot stellar cores, each the ashes of the previous nuclear burn phase, would work up the chain of alpha elements of the periodic table as far as the mass of the star would provide pressure and therefore heat: C-12, O-16, Ne-20, Mg-24, Si-28, Ar-36, Ca-40, …, Fe-56. If the mass of the star provides enough pressure and heat to support multiple phases of nuclear burning, the star will evolve into an onion layer configuration of burning shells, expelling as much as 25% of its mass into the interstellar medium by way of stellar winds. In the most massive stars, the creation of heavier elements does not stop until iron (Fe) is reached. Fe lies at the bottom of the curve of binding energy, so it is the ultimate, unburnable nuclear ash, and relatively plentiful.

In the nuclear burning layers of the star, elements with atomic number (number of protons) higher than that of Fe are created endothermically during the late phases in the life of a massive star due to the "S-process", in which neutrons are absorbed, building up the total number of nucleons (neutrons and protons) in the nucleus. In this S-process (S for slow) the excess of neutrons in an isotope has time to adjust itself via the weak interaction before another neutron can be captured, by converting a neutron into a proton, spitting out an electron to balance the total electric charge. This conversion adds a proton and thereby creates a species one step higher up on the periodic table. Thus, many of the heavier elements can be forged before the star comes to the end of its nuclear burning life by either 1) running out of fuel, and blowing off its outer lays in a planetary nebula, or 2) exploding as a type II supernova. The S-process cannot go beyond Bi and fails to populate the neutron-rich isotopes.

The neutron-rich isotopes, and elements beyond Bi, are built in a few violent seconds during a type II supernova explosion. Neutron fluxes are huge, and neutron-rich isotopes are built up before they have a chance to decay.

Type I supernovas convert carbon-oxygen white dwarfs into the iron group elements.

Iron cores in stars, type II supernovae, the "urca" process, neutrino detection, and the neutrino background:
In a star with more than about nine solar masses, nuclear burning eventually produces an iron core which grows and compresses against the forces of nuclear degeneracy until finally it collapses under its own weight in a fraction of a second. The collapsed remnant, which consists of several solar masses of nuclear density material, is a neutron star. If it is massive enough, it continues collapsing through its event horizon, becoming a black hole. In either case, the enormous amount of gravitational energy released in the collapse of the iron core gives rise to a supernova explosion, which can greatly outshine, for a few days, a large, spiral galaxy. The dominant theory for the mechanism of the explosion invokes a shock wave bouncing off the collapsed core, and a massive outpouring of thermal neutrinos from a 100 billion degree core, 1% of which are absorbed by the layers of the star. The details are not well understood, but it is the "received wisdom" that the energy and outward momentum of the shock, and these neutrinos, and the interaction of the neutrinos and the shock, which drives the explosion and heats

the expanding material. Ninety-nine % of the neutrinos are lost to space, streaking off at approximately the speed of light.

It follows that over cosmic time scales these neutrinos would populate the intergalactic medium and intercluster voids. In addition, there is thought to be a neutrino background from the Big Bang at about 1-2 seconds (T = 2.5 MeV), analogous to the cosmic microwave background (CMB), which formed at 380,000 years. As the universe expands, relativistic red shift reduces the energy of all neutrinos just as it does the photons in the CMB. Background neutrinos have a temperature today of 1.9 K, which may be too weak for observation, as low energy neutrinos are notoriously hard to detect. If this background could be observed in detail it would no doubt reveal a great deal about the early universe.

Observational confirmation of the Urca process: Fifteen neutrinos from SN1987A were detected at the newly constructed Kamiokande detector in Japan. This was the first detection of extra-solar neutrinos, and a very important confirmation of the so called "urca process". More underground neutrino detectors await the next nearby supernova. Neutrinos are thought to have a small amount of mass. This raises the question of their propagation velocity, and the timing of supernova light vs neutrino arrival is one way of estimating this. From their arrival time, the SN1987A neutrinos had to be moving at approximately the speed of light, but it is impossible to refine their timing and that of the SN's light to be more specific about their speed.

58. Salpeter, Edward 1924 - 2008
Austrian-American physicist who predicted the two-step process by which He-4 could be fused into C-12. See Hoyle.

Salpeter also estimated the distribution of stars over mass, called the "initial mass function". Later in his life he led a committee which investigated and shot down the claims of President Reagan's SDI (Star Wars) proponents.