



- Electrons
- Neutrinos
- Mus
- Taus

LEPTONS



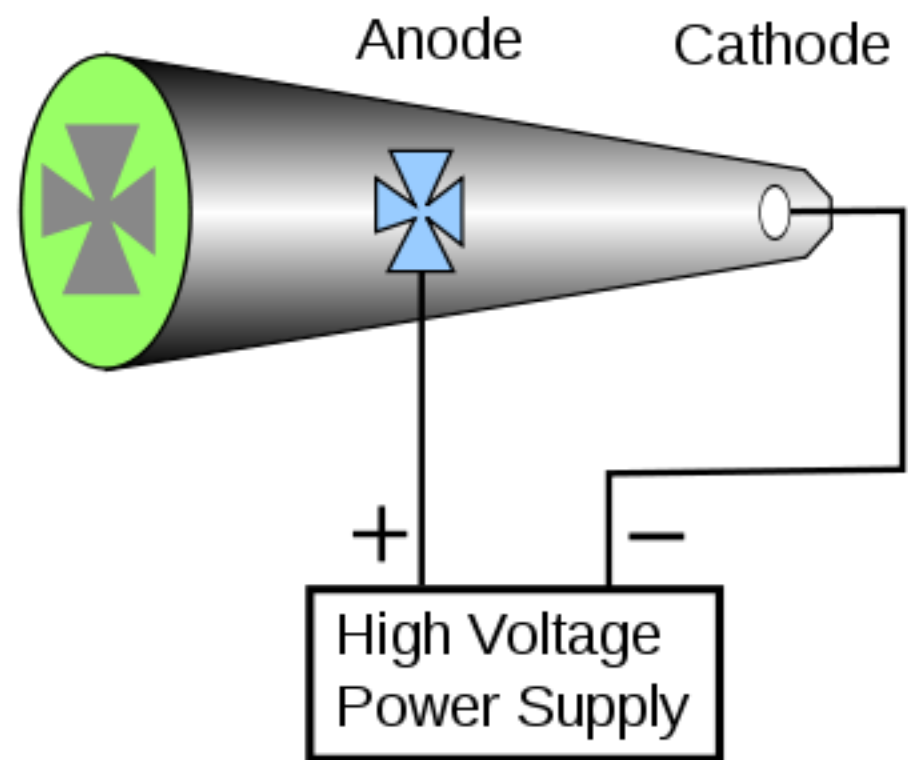
Sir

**J. J. Thomson**

OM PRS

# JOSEPH JOHN THOMPSON (1856-1940)

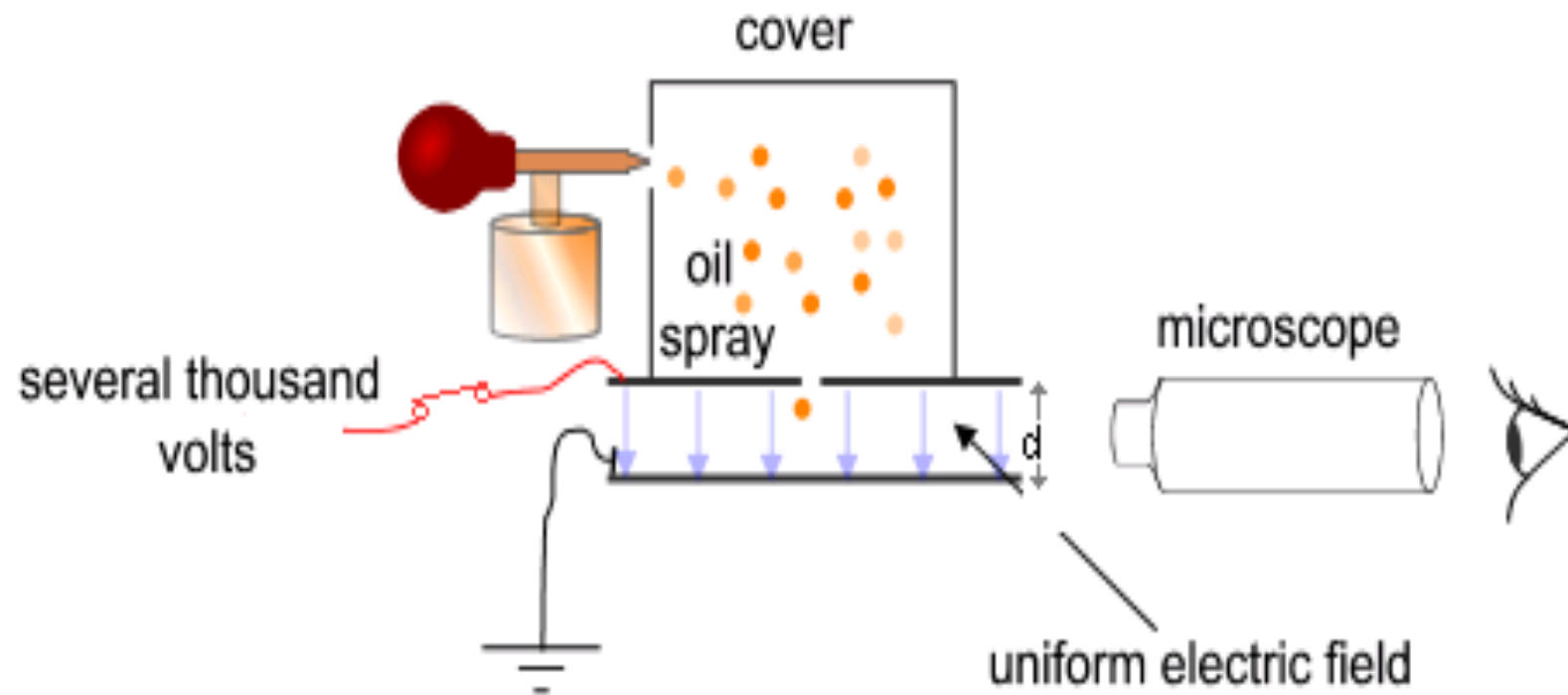
- By the mid 19<sup>th</sup> century the CATHODE RAY TUBE had been discovered and was a popular gadget. CATHODE RAYS were assumed to travel from the CATHODE (- charged) to the ANODE (+ charged) and were assumed to be the size of atoms.
- Early tubes still had about 1% of the air still in them, so the rays were being formed by the ionization of air molecules around the cathode.
- Thompson showed that the rays travelled in air much further than any atom-sized particles could, so they must be particles thousands of times smaller than atoms. He also showed that cathode rays with other types of gas in the tubes gave the same rays.
- In 1897 he showed that electric fields deflected the rays and measured their CHARGE-TO-MASS ratio. In 1906 He received the NOBEL PRIZE for discovering the ELECTRON.



# ELECTRON

- Stable. Indestructible, the only way to get rid of one is to annihilate it by reacting it with its anti-particle.
- Its anti-particle has its own name, POSITRON, which is exactly like it but with the opposite electrical charge.
- BETA DECAY, is the radioactive emission of either an electron or a positron (or the capture by the nucleus of an orbital electron). The creation of the electron is accompanied by the creation of an anti-electron neutrino and the creation of a positron is accompanied by the creation of an electron neutrino. The electron capture is accompanied by the emission of an electron neutrino. In all cases the lepton number is preserved.

# ROBERT MILLIKAN (1868-1953) 1906



# FLAVOR 1

PARTICLE	MASS (AMU)	MASS (Mev)	ELECTRIC CHARGE	WEAK CHARGE	SPIN
Electron	0.0054	0.511	-1	-1/2	1/2
Electron neutrino	$< 10^{-8}$	$< 2 \times 10^{-6}$	0	1/2	1/2

# MUON

- Mean life is  $2.2 \times 10^{-6}$  seconds.
- Decays into an electron and an anti-electron neutrino and a muon neutrino.
- Again, the number of family members must be conserved, so the muon neutrino replaces the muon, and the electron and its electron anti-neutrino cancel.
- Over 105 million electron volts of kinetic energy is shared among the electron and the two neutrinos.



# FLAVOR 2

PARTICLE	MASS (AMU)	MASS (Mev)	ELECTRIC CHARGE	WEAK CHARGE	SPIN	HALF_LIFE
Muon	0.11	105.7	-1	-1/2	1/2	$2.2 \times 10^{-6}$ second
Muon-neutrino	<0.0003	<0.19	0	1/2	1/2	stable

# TAU

- Mean life is  $2.9 \times 10^{-13}$  seconds.
- Decays into an electron and an anti-electron neutrino plus a tau neutrino.
- The number of family members, being Fermions, must be conserved, so the tau-neutrino takes the place of the tau, while the electron and anti-electron neutrino together keep the number of "flavor 1" leptons at a net zero.
- Because of the great rest mass of the Tau, over 1.776 billion electron volts of energy appears as the kinetic energy of the products.

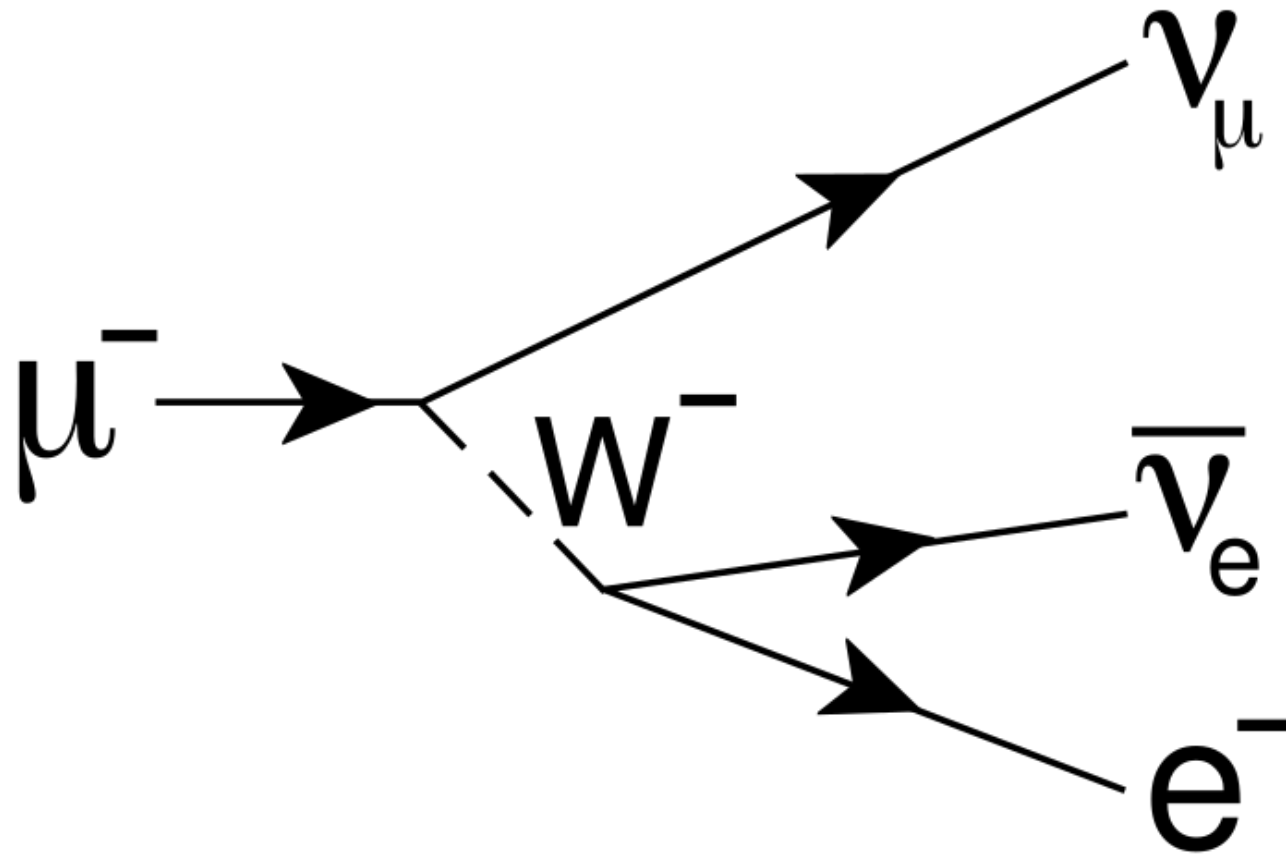
# FLAVOR 3

PARTICLE	MASS(AMU)	MASS(Mev)	ELECTRIC CHARGE	WEAK CHARGE	SPIN	HALF-LIFE
Tau	1.9	1,777	-1	-1/2	1/2	$2.9 \times 10^{-13}$ seconds
Tau-neutrino	<0.33	<18	0	1/2	1/2	stable

# THE FOUR FORCES

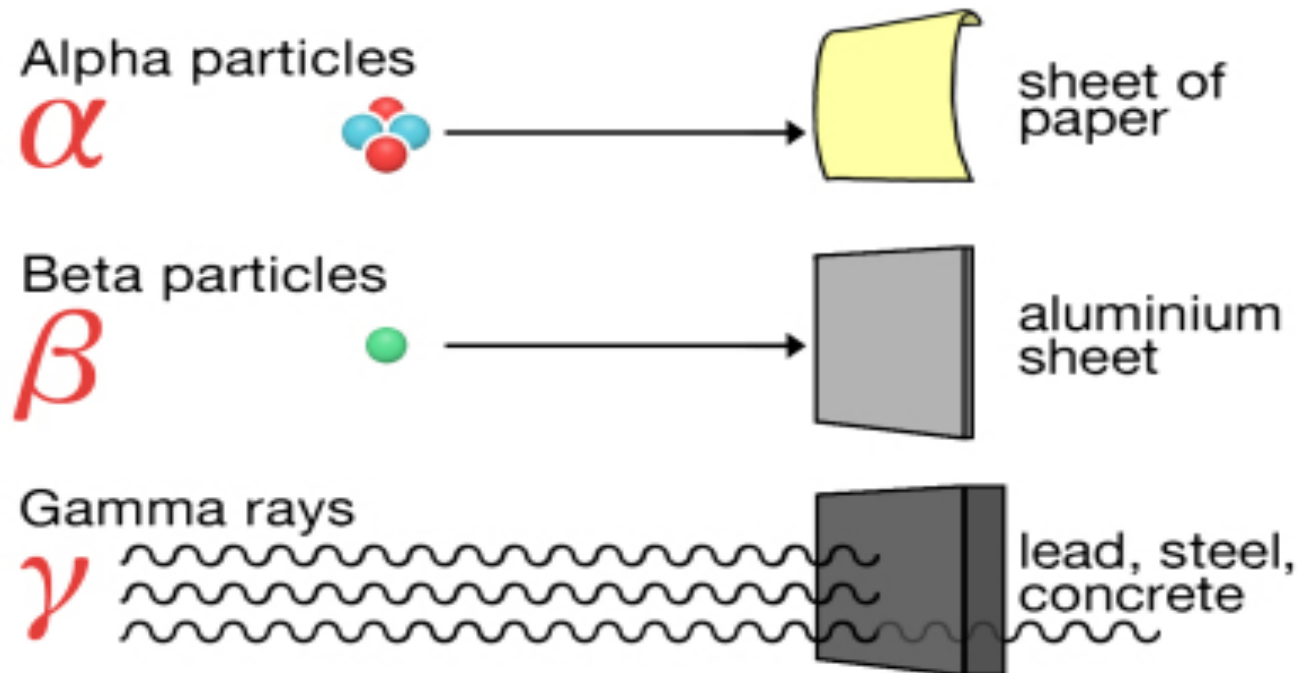
- The STRONG force. Force carrier is the BOSON GLUON, and is attractive only. The strong force holds nuclei together and is active when BARYONS interact. The force is zero for baryons in virtual contact and increases with separation, making it impossible to separate QUARKS.
- The ELECTRIC force. Runs our lives as electricity. Is both attractive and repulsive, depending upon charges. Follows an inverse-square of distance law.
- The WEAK force. Force is involved in BETA DECAY only. Force carriers are the Z and W BOSONS. By weird mathematical manipulation, the WEAK and ELECTRIC forces can be united to form a single force if the general energy level is high enough (The two were combined in the early days of the universe).
- The GRAVITATIONAL force. Weakest of all, is attractive only and follows an inverse-square of distance law. The force carrier is the GRAVITON, but gravity is such a weak force that it takes Black holes colliding to generate a graviton strong enough to be detected. GENERAL RELATIVITY sees GRAVITY as a property of space-time itself.

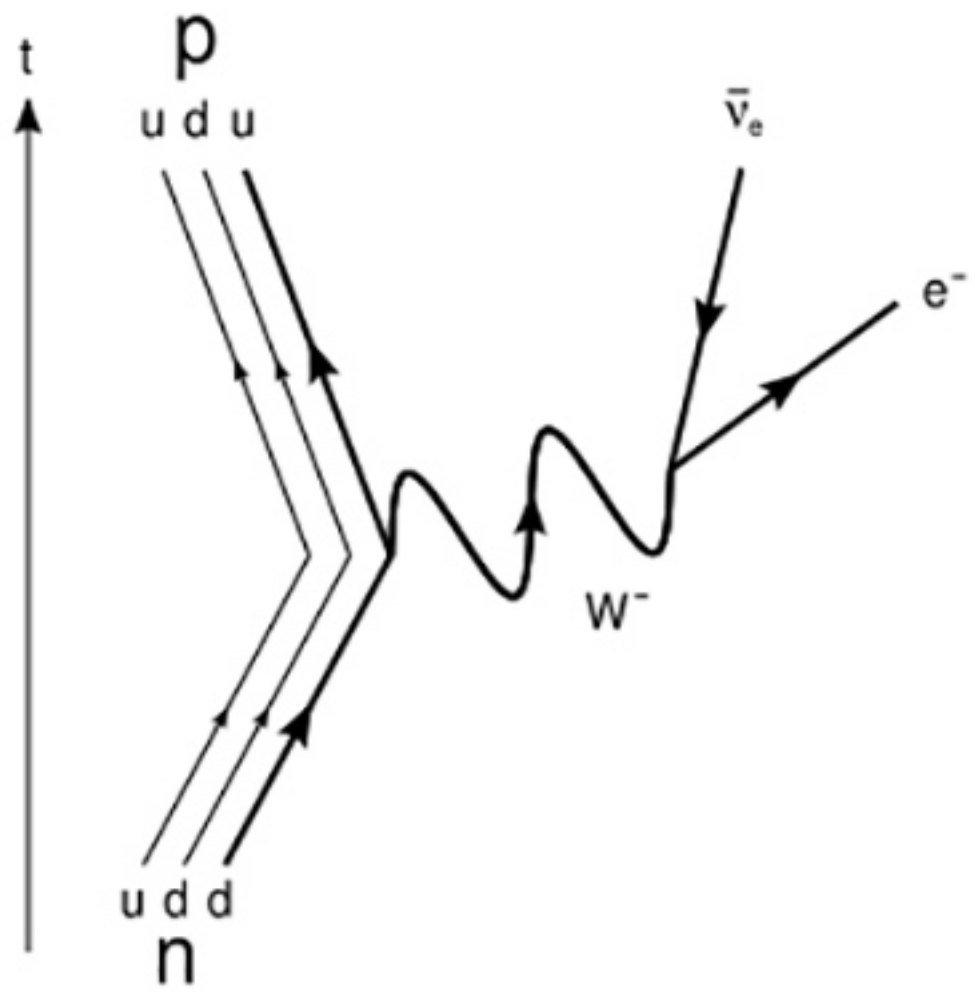
# $W^-$ BOSON IN MUON DECAY



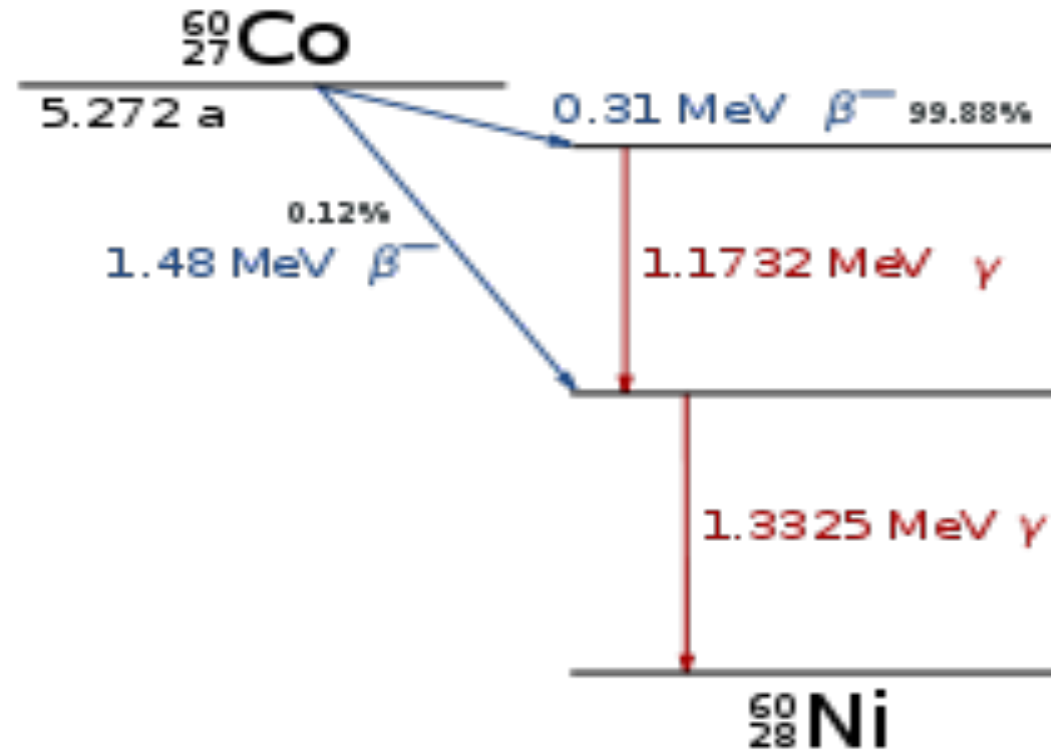
# RADIOACTIVITY

## WHAT IT TAKES TO STOP RADIATION



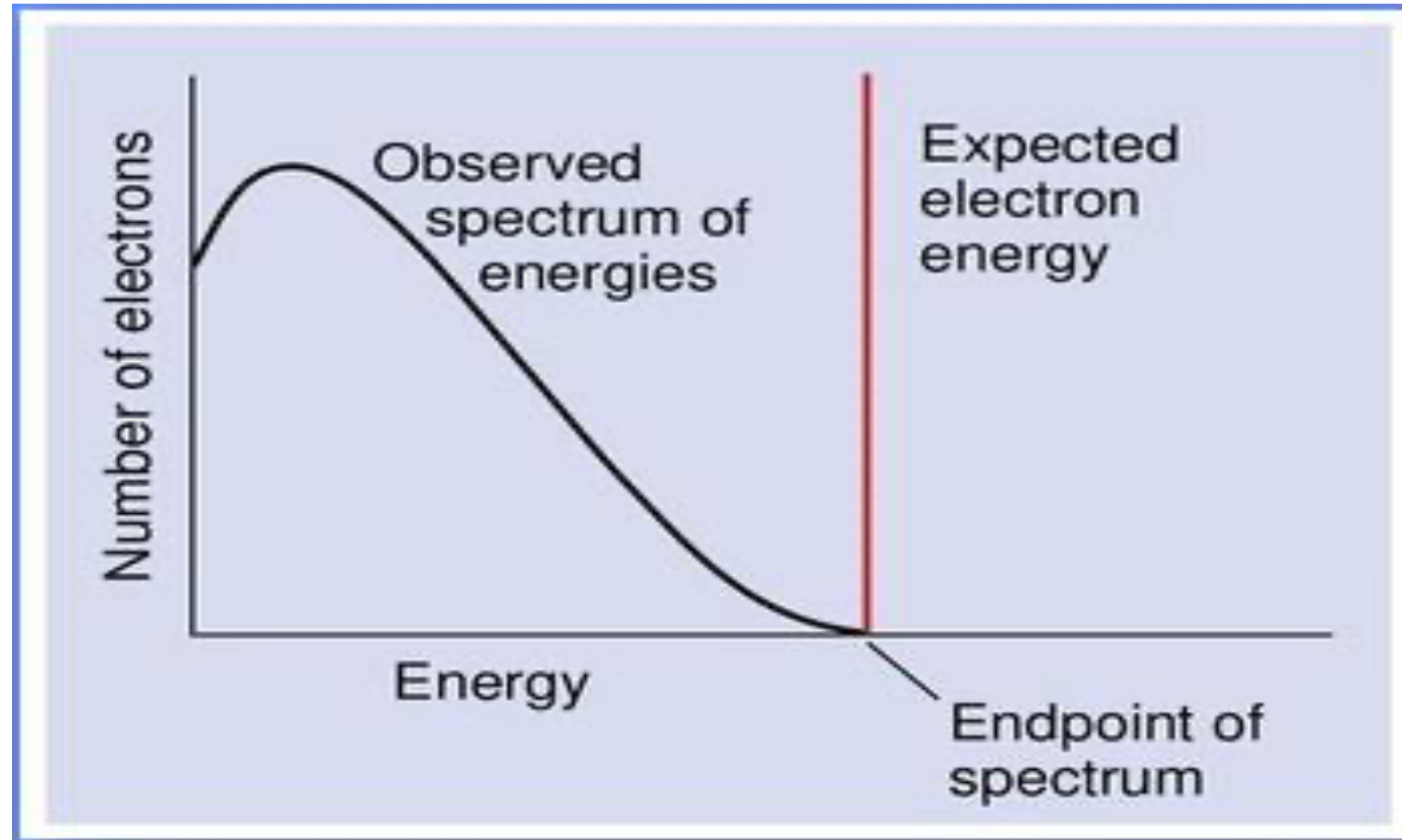


# BETA DECAY EXAMPLE $^{60}\text{Co}$





# MASS OF NEUTRINOS



# NEUTRINO DETECTION

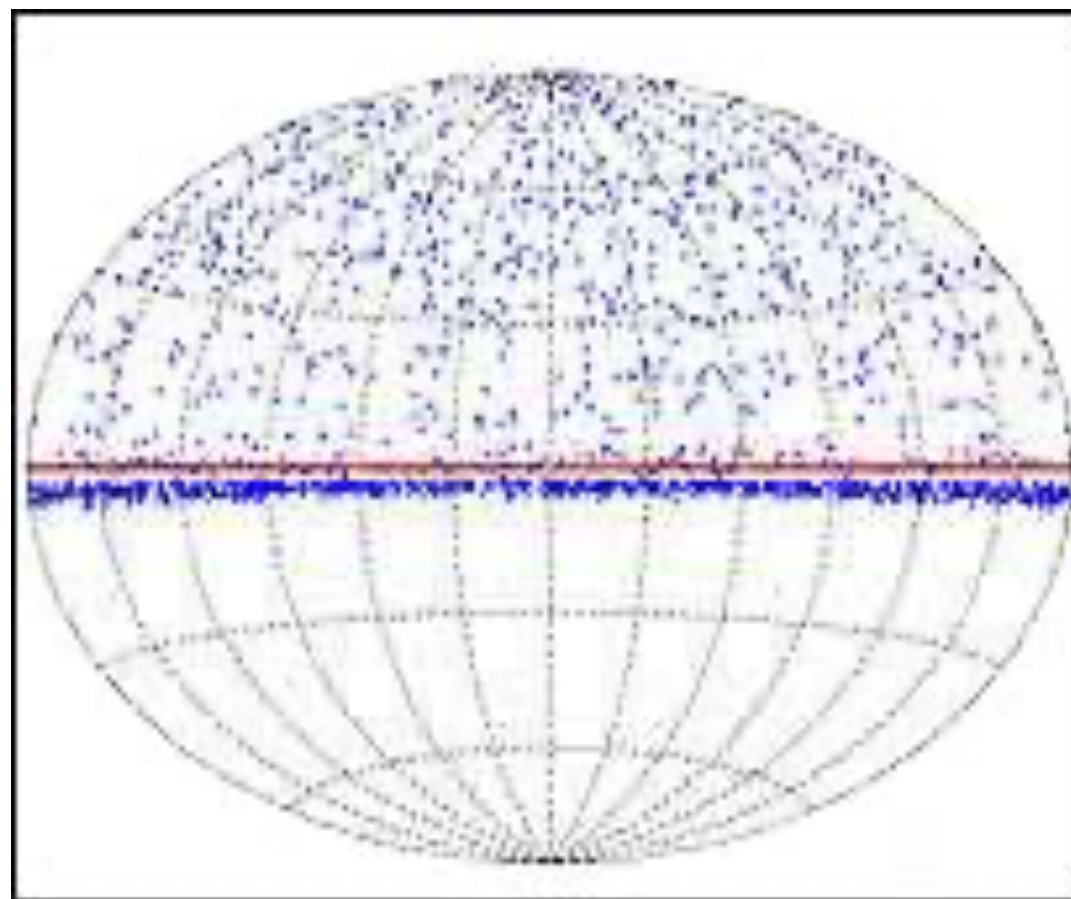
- Neutrinos are abundant and omnipresent. Each second tens of billions pass through every square centimeter of space... including the space our bodies inhabit. They are so poorly interactive with other forms of matter that the Earth affords no shadowing effect, and neutrinos are coming up out of the ground as much as from above.
- The earliest detectors used huge pools of water observed by many scintillation counters. A 1.8 MeV electron-anti-neutrino can react with a proton to form a NEUTRON and a positron, allowing the annihilation of the positron to be observed by the counters. [Antineutrinos](#) were first detected near the [Savannah River nuclear reactor](#) by the [Cowan–Reines neutrino experiment](#) in 1956. [Frederick Reines](#) and [Clyde Cowan](#) used two targets containing a solution of cadmium chloride in water. Two [scintillation](#) detectors were placed next to the water targets. Antineutrinos with an energy above the [threshold](#) of 1.8 [MeV](#) caused charged current "inverse beta-decay" interactions with the protons in the water, producing positrons and neutrons. The resulting positron annihilations with electrons created pairs of coincident photons with an energy of about 0.5 MeV each, which could be detected by the two scintillation detectors above and below the target. The neutrons were captured by cadmium nuclei resulting in delayed gamma rays of about 8 MeV that were detected a few microseconds after the photons from a positron annihilation event.
- This experiment was designed by Cowan and Reines to give a unique signature for antineutrinos, to prove the existence of these particles. It was not the experimental goal to measure the total antineutrino [flux](#). The detected antineutrinos thus all carried an energy greater than 1.8 MeV, which is the threshold for the reaction channel used (1.8 MeV is the energy needed to create a positron and a neutron from a proton). Only about 3% of the antineutrinos from a nuclear reactor carry enough energy for the reaction to occur.

# Cherenkov detectors

- "Ring-imaging" Cherenkov detectors take advantage of a phenomenon called [Cherenkov light](#). Cherenkov radiation is produced whenever charged particles such as electrons or muons are moving through a given detector medium somewhat faster than the [speed of light in that medium](#). In a Cherenkov detector, a large volume of clear material such as water or ice is surrounded by light-sensitive [photomultiplier](#) tubes. A charged lepton produced with sufficient energy and moving through such a detector does travel somewhat faster than the speed of light in the detector medium (although somewhat slower than the speed of light in a [vacuum](#)). The charged lepton generates a visible "optical shockwave" of [Cherenkov radiation](#). This radiation is detected by the photomultiplier tubes and shows up as a characteristic ring-like pattern of activity in the array of photomultiplier tubes. As neutrinos can interact with atomic nuclei to produce charged leptons which emit Cherenkov radiation, this pattern can be used to infer direction, energy, and (sometimes) flavor information about incident neutrinos.
- Two water-filled detectors of this type (Kamiokande and [IMB](#)) recorded a neutrino burst from supernova [SN 1987A](#). Scientists detected 19 neutrinos from an explosion of a star inside the Large Magellanic Cloud—only 19 out of the octodecillion ( $10^{57}$ ) neutrinos emitted by the supernova. The Kamiokande detector was able to detect the burst of neutrinos associated with this supernova, and in 1988 it was used to directly confirm the production of solar neutrinos. The largest such detector is the water-filled [Super-Kamiokande](#). This detector uses 50,000 tons of pure water surrounded by 11,000 photomultiplier tubes buried 1 km underground.
- The [Sudbury Neutrino Observatory](#) (SNO) uses 1,000 tonnes of [ultrapure heavy water](#) contained in a 12-metre-diameter vessel made of acrylic plastic surrounded by a cylinder of ultrapure ordinary water 22 metres in diameter and 34 metres high. In addition to the neutrino interactions visible in a regular water detector, a neutrino can break up the deuterium in heavy water. The resulting free neutron is subsequently captured, releasing a burst of gamma rays that can be detected. All three neutrino flavors participate equally in this dissociation reaction.

# Radiochemical methods

- Chlorine detectors, based on the method suggested by [Bruno Pontecorvo](#), consist of a tank filled with a chlorine containing fluid such as [tetrachloroethylene](#). A neutrino converts a [chlorine-37](#) atom into one of [argon-37](#) via the charged current interaction. The threshold neutrino energy for this reaction is 0.814 MeV. The fluid is periodically purged with [helium](#) gas which would remove the argon. The helium is then cooled to separate out the argon, and the argon atoms are counted based on their [electron capture](#) radioactive decays. A chlorine detector in the former [Homestake Mine](#) near [Lead, South Dakota](#), containing 520 [short tons](#) (470 [metric tons](#)) of fluid, was the first to detect the solar neutrinos, and made the first measurement of the deficit of electron neutrinos from the sun (see [Solar neutrino problem](#)).
- A similar detector design, with a much lower detection threshold of 0.233 MeV, uses a [gallium](#) → [germanium](#) transformation which is sensitive to lower-energy neutrinos. A neutrino is able to react with an atom of gallium-71, converting it into an atom of the unstable isotope [germanium-71](#). The germanium was then chemically extracted and concentrated. Neutrinos were thus detected by measuring the radioactive decay of germanium. This latter method is nicknamed the "[Alsace-Lorraine](#)" technique because of the reaction sequence (gallium-germanium-gallium) involved. Gallium and germanium are named after France and Germany, respectively, and ownership of the Alsace-Lorraine territory has historically been a point of contention between France and Germany, thus the nickname of the technique. These radiochemical detection methods are useful only for counting neutrinos; no neutrino direction or energy information is available. The [SAGE](#) experiment in Russia used about 50 tons, and the [GALLEX/GNO](#) experiments in Italy about 30 tons, of [gallium](#) as reaction mass. This experiment is difficult to scale up due to the prohibitive cost of gallium. Larger experiments have therefore turned to a cheaper reaction mass.



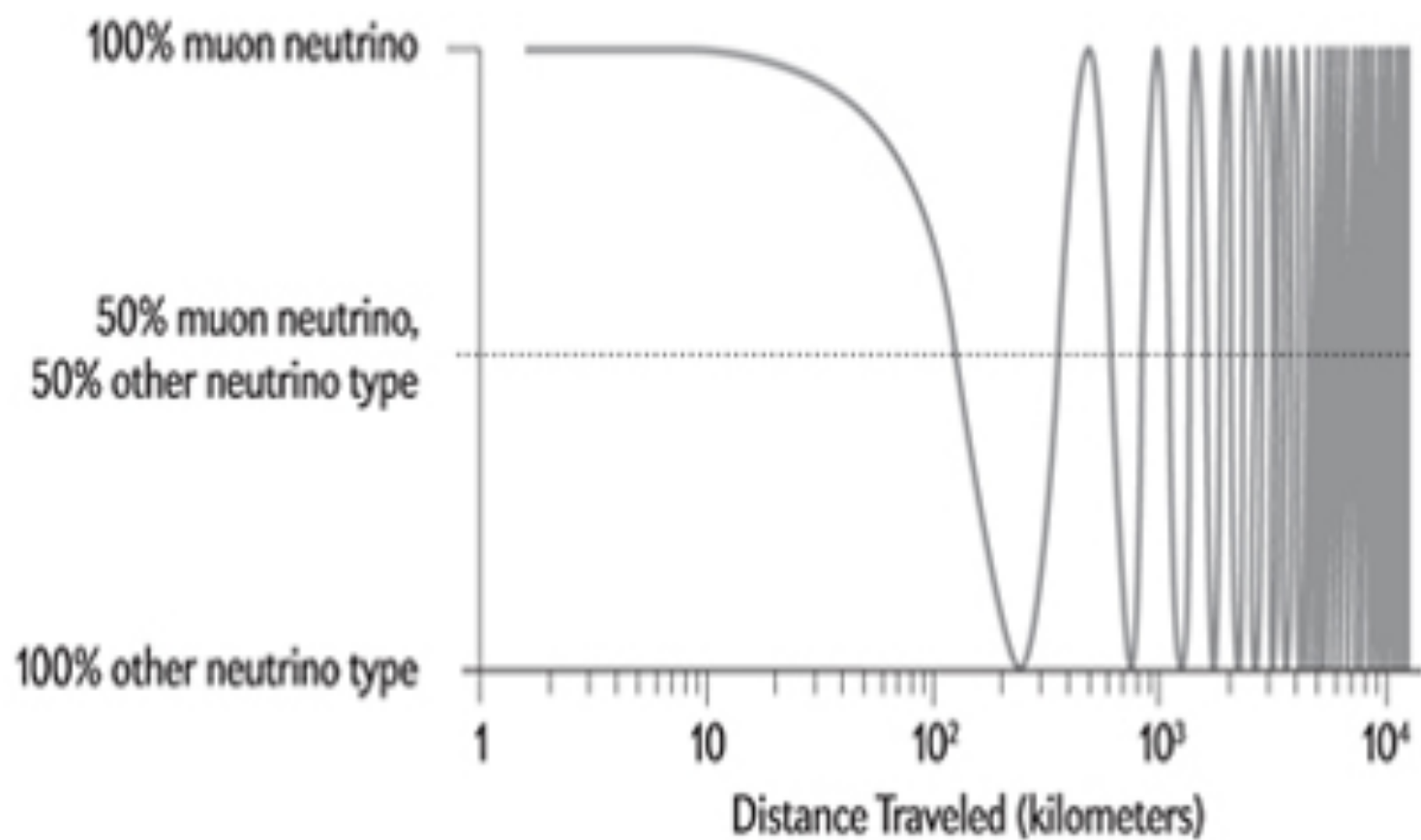
The first ever map of the neutrino sky has been produced by a novel telescope encased in ice at the South Pole.

- Amanda 2 (Antarctic Muon and Neutrino Detector Array - 2) is designed to look not up, but down, through the Earth to the sky of the Northern Hemisphere.
- It comprises 677 glass optical modules, each the size of a bowling ball, arrayed on 19 cables set deep in the ice forming a cylinder 500 metres in height and 120 metres in diameter.
- Unlike most other detection methods, coherent scattering does not depend on the flavor of the neutrino. The neutrino scatters off the nucleus as a whole, rather than individual quarks.

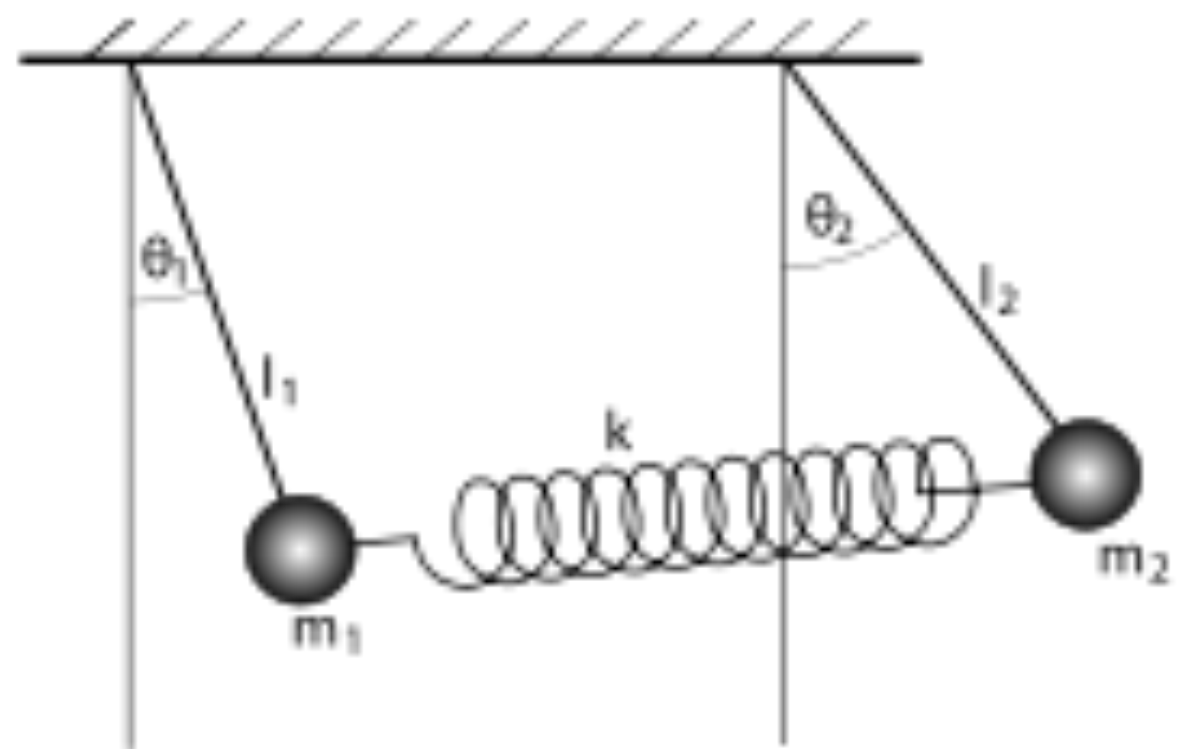
# THE NEUTRINO “SCARE”

- In the 1970s it was discovered that the neutrinos coming out of the sun were insufficient to match the current models of solar nuclear reactions.
- Electron, mu, and tau neutrinos and anti-neutrinos oscillate amongst themselves. An electron neutrino coming from the sun will change into a mu or tau and then change back again.
- But the three flavors of neutrino have slightly different masses, complicating the propagation of the neutrinos.

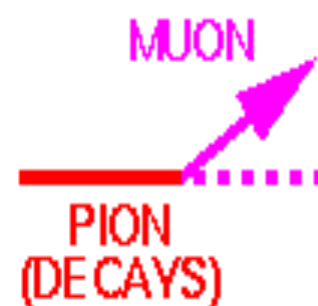
## Neutrino Oscillations



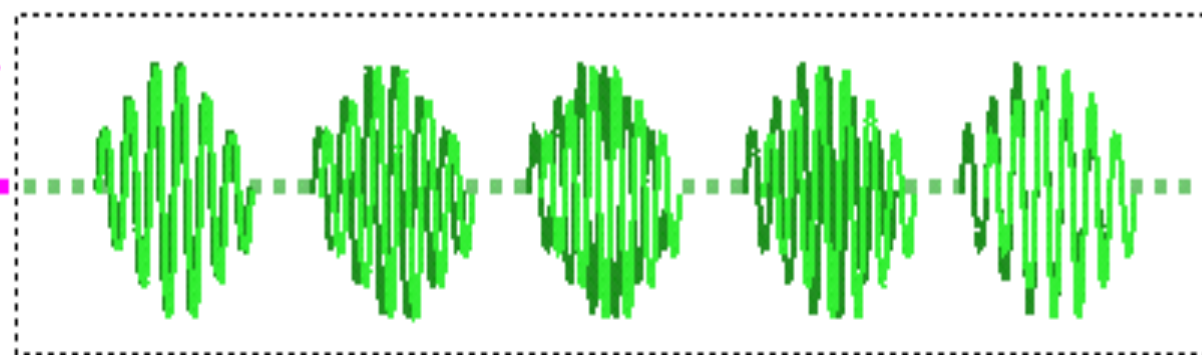




MUON NEUTRINO  
CREATED IN THE  
UPPER ATMOSPHERE

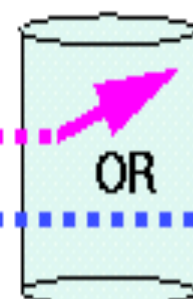


TWO WAVE PACKETS OF  
DIFFERENT MASS TRAVEL  
AT DIFFERENT VELOCITIES



INTERFERENCE PATTERN OF WAVE PACKETS DETERMINES  
PROBABILITY OF THE NEUTRINO FLAVOR

WHICH FLAVOR IS  
DETECTED DEPENDS  
ON THE INTERFERENCE  
PATTERN AT SUPER-K

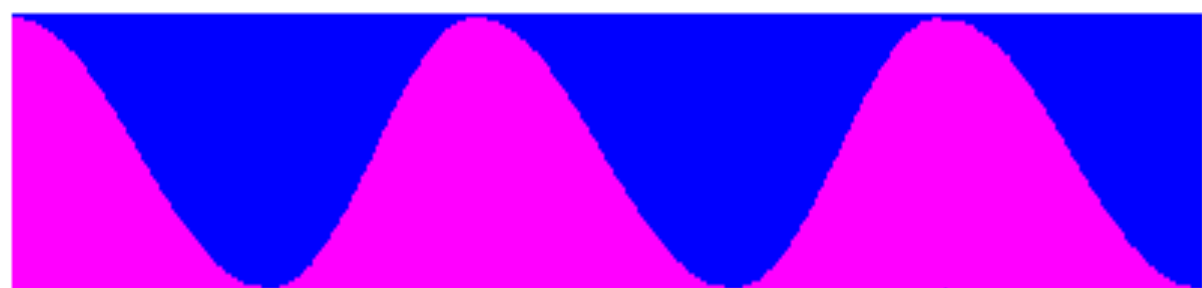


MUON

NOT  
ENOUGH  
ENERGY  
TO MAKE TAU

100% MUON  
NEUTRINO

0% TAU  
NEUTRINO



100% TAU  
NEUTRINO

0% MUON  
NEUTRINO

# THE “Z-NAUGHT” BOSON

- The  $Z^0$  boson is its own antiparticle. Thus, all of its flavour quantum numbers and charges are zero. The exchange of a Z boson between particles, called a neutral current interaction, therefore leaves the interacting particles unaffected, except for a transfer of spin and/or momentum.  
Z boson interactions involving neutrinos have distinct signatures: They provide the only known mechanism for elastic scattering of neutrinos in matter; neutrinos are almost as likely to scatter elastically (via Z boson exchange) as inelastically (via W boson exchange). Recall the  $W^+$ ,  $W^-$  (which are anti-particles of one another) and  $Z^0$  bosons are the force carriers of the WEAK FORCE.

# WERNER HEISENBERG (1901-1976)



# HEISENBERG'S UNCERTAINTY PRINCIPLE

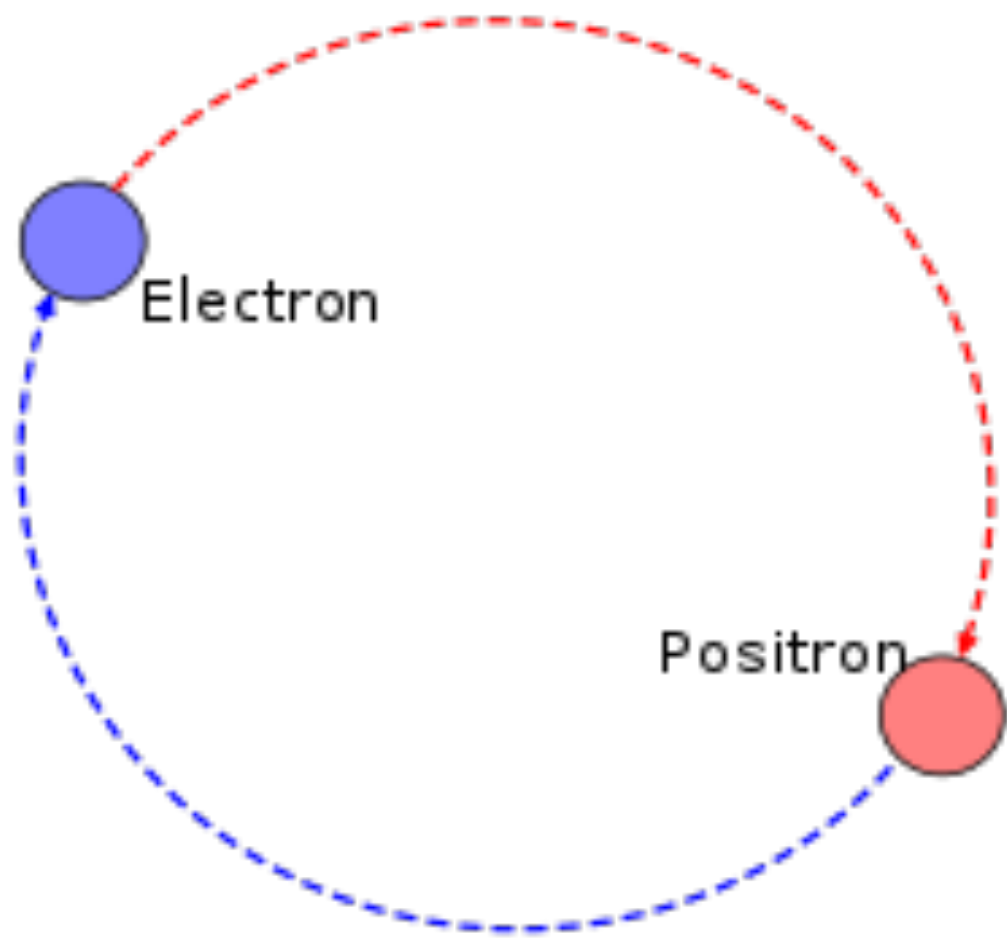
- Originally, the UNCERTAINTY PRINCIPLE was conceived as an observational limit: to observe a small object required bouncing a light or other probe upon it, and if the object observed was small enough it would be perturbed by the act of observing it.
- The uncertainty, however, arises from the basic premises of quantum mechanics. Observables are associated with OPERATORS, and if the operators of two observable quantities DO NOT COMMUTE, then these observables cannot both be known exactly.
- Energy and time as well as mass and energy form pairs that can affect the precision of their measurements.

# HEISENBERG

- Led Nazi Germany's "Manhattan Project."
- In 1925 he reformulated quantum mechanics in terms of matrices, for which he received the NOBEL PRIZE in 1932, at age 31.
- He visited occupied Copenhagen to try to convince Bohr of the inevitability of Nazi victory.
- His version of Fermi's Chicago pile was a bunch of uranium cubes suspended by wires. He deduced (incorrectly) that the critical mass would be too large for delivery as a bomb and went directly for the hydrogen bomb without a fission trigger.
- He was imprisoned in Britain briefly after VE day, but then returned to Germany to lead an academic life.

# COLD FUSION

- Primary COSMIC RAYS in upper atmosphere smash air into sprays of new particles, including leptons and antileptons.
- Because of LORENTZ CONTRACTION, the fast-moving MUS are able to get to ground level.
- DEUTERIUM (“heavy hydrogen”) molecules are held together by two electrons. MU particles are 207 times more massive than electrons, and the binding force is linear in lepton mass.
- $D + D \rightarrow {}^3\text{He} + n$





# POSITRONIUM

- The mass of positronium is 1.022 MeV, which is twice the electron mass minus the binding energy of a few eV. The [ground state](#) of positronium, like that of hydrogen, has two possible configurations depending on the relative orientations of the spins of the electron and the positron.
- The SINGLET STATE, with [antiparallel spins](#) ( $S = 0, M_s = 0$ ) is known as *para*-positronium (*p*-Ps). It has a mean lifetime of 0.12 [ns](#) and decays preferentially into two gamma rays with energy of 511 [keV](#) each (in the [center-of-mass frame](#)). By detecting these photons the position at which the decay occurred can be determined. This process is used in [positron-emission tomography](#) ( a PET SCAN). *Para*-positronium can decay into any even number of photons (2, 4, 6, ...), but the probability quickly decreases with the number: the [branching ratio](#) for decay into 4 photons is  $1.439(2) \times 10^{-6}$ .
- The [triplet state](#),  $^3S_1$ , with [parallel](#) spins ( $S = 1, M_s = -1, 0, 1$ ) is known as *ortho*-positronium (*o*-Ps). It has a mean lifetime of  $142.05 \pm 0.02$  ns, and the leading decay is three gammas. Other modes of decay are negligible; for instance, the five-photons mode has branching ratio of  $\approx 10^{-6}$ .

# “COLD” FUSION

- It all got started in 1989, when electrochemists Martin Fleischmann and Stanley Pons [made the stunning announcement](#) at a press conference at the University of Utah that they had tamed the power of nuclear fusion in an electrolysis cell.
- After months of investigating Fleischmann and Pons’s puzzling observations, however, the [scientific community came to a consensus](#) that the effect was inconsistent or nonexistent and that the scientists had made experimental errors. The research was summarily condemned, and cold fusion became a synonym for junk science.

# MUONS AS A SUBSTITUTE FOR ELECTRONS

- The Schrödinger equation for the FORCE between two atoms holding them in a diatomic molecule is linear in the mass of the electron.
- The MU MINUS LEPTON is just like its cousin the ELECTRON except that it has 207 times the mass and a half-life of 2.2 microseconds.
- If a MU MINUS comes anywhere near any molecule it will be strongly attracted to it, and will replace the electrons in that molecule.
- If the molecule is of very low atomic number, the force of the mu holding the atoms together will approach the Coulomb barrier preventing them from fusing.

# MUON CATALYZED FUSION

- Mechanisms for cold fusion had been contemplated as early as 1926. In fact, as early as 1934, scientists were speculating about hydrogen dissolved in palladium in relation to nuclear fusion. [3] An alternate mechanism, muon-catalyzed fusion, was studied by Andrei Sakharov and later observed by Luis Alvarez in 1956, but, according to Lewenstein and Baur's chronology of cold fusion, scientists decided that this particular mechanism was "not likely to be a panacea."
- By the mid-1980s, two cold fusion research efforts that would come to gain widespread attention in 1989 were underway: the collaboration between Pons and Fleischmann at the University of Utah, and the work of Steven Jones and colleagues at Brigham Young University. [3] Both efforts attempted to produce D-D fusion, with two possible reactions under consideration:  ${}^2\text{H} + {}^2\text{H} \rightarrow {}^3\text{He} + \text{n}$  and  ${}^2\text{H} + {}^2\text{H} \rightarrow {}^3\text{H} + {}^1\text{H}$ .
- (or  $\text{D} + \text{D} \rightarrow {}^3\text{He} + \text{n}$  and  $\text{D} + \text{D} \rightarrow \text{T} + \text{p}$ )

