

# The Discovery of Antimatter

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Physics 290E

# The Many Uses of Antimatter

- Rarely seen, yet popular in sci-fi
  - Only ~100 nanograms created by humans
  - $|\eta| = \left| \frac{n_b - \bar{n}_b}{s} \right| \leq 6 \times 10^{-27}$
- Medicine:
  - Positron Emission Tomography (PET) uses radioactive isotopes injected into body to create positrons that annihilate with electrons creating gamma rays used to construct images.
- Fuel:
  - Famously used by the starship Enterprise for FTL travel in *Star Trek*
  - And actually studied in simulation to test efficiency
- Weapons:
  - Cannot forget Professor Langdon's heroic struggle to save the Vatican from an antimatter bomb in "Angels and Demons"
  - And unsurprisingly studied by the U.S. Air Force during the Cold War as a possible explosive.

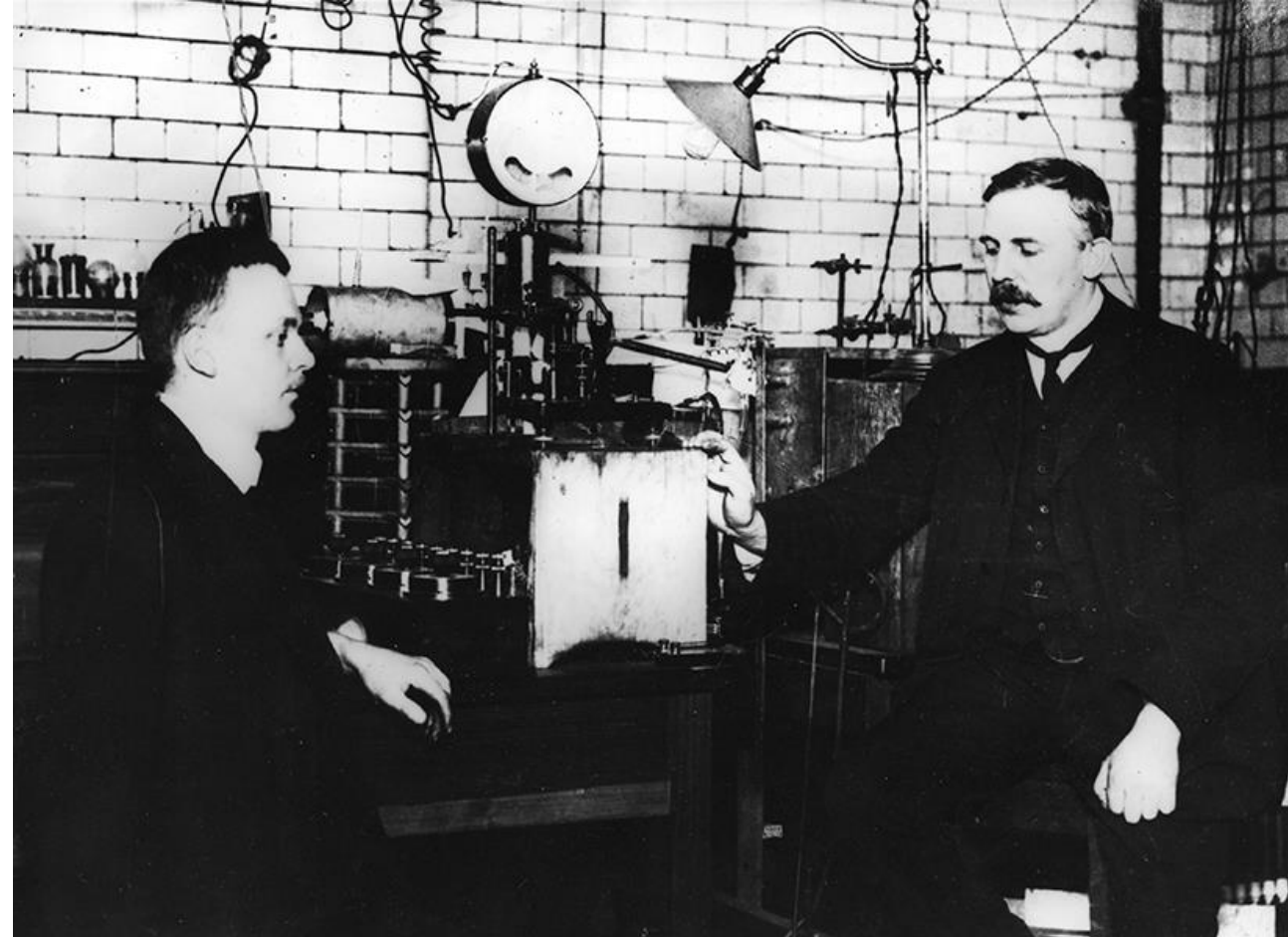
# Historical Context

- 1897: JJ Thomson discovers the electron (“plum pudding” model of atom)
  - See Patrick’s talk!!



# Historical Context

- 1911/1919: Rutherford puts forth the theory that atoms had a small, charged nucleus made up of protons. The proton later discovered as a positively charged Hydrogen.
  - Based on experiment carried out by Hans Geiger and Ernest Marsden where alpha particles are shot at thin gold foil in 1909 and Nitrogen in 1919.



# Historical Context



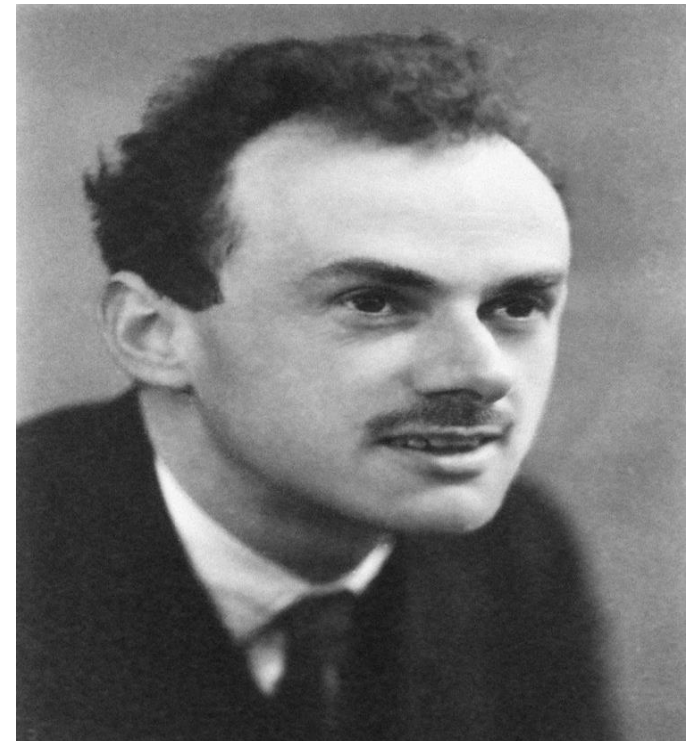
- 1932: Based on experiment carried out by Irene Curie and Frederic Joliot a year earlier, James Chadwick discovers the neutron.
  - Used alpha sources from Polonium decay to smash Beryllium and observe final radiation.  $He_2^4 + Be_4^9 \rightarrow C_6^{12} + n_0^1$
- So we've got everything to create observable matter. What more do we need?

# Dirac's Bold Statement

- Positive and Negative energy states as a result of Dirac's equation for fermions
- Negative Energy results in a in an "Infinite Sea" interpretation by Dirac
  - Electron would "runaway" to increasingly negative states if it weren't for the filled infinite sea.
- Feynman-Stuckelberg formulation to the rescue:
  - Absence of **negatively** charged, **negative** energy state is a presence of a **positively** charged, **positive** energy state – the positron.

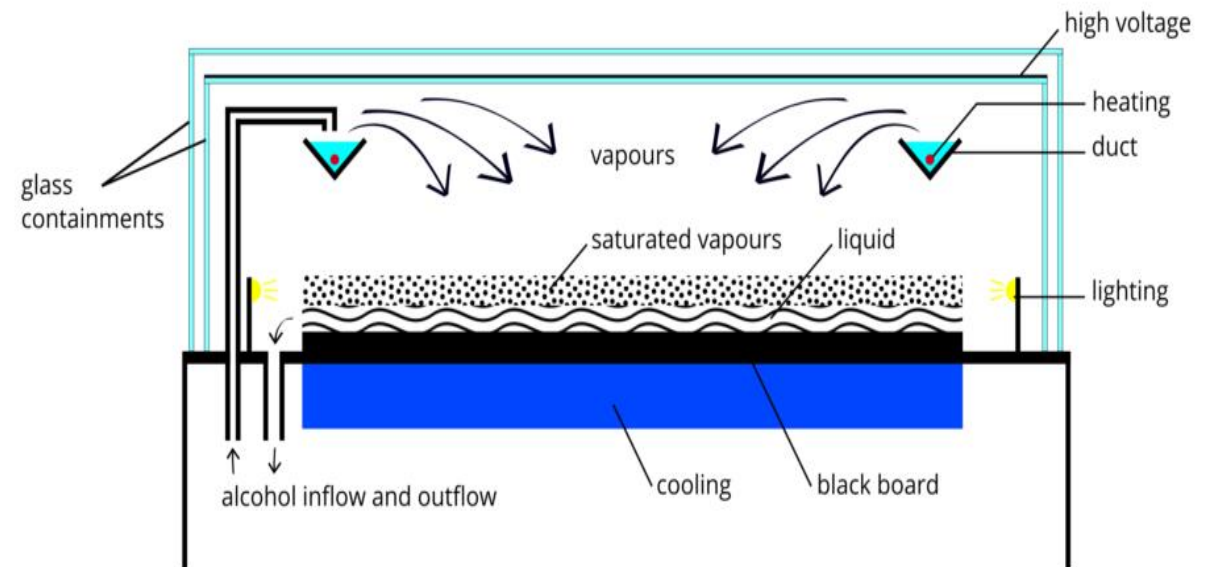
$$E = +\sqrt{\mathbf{p}^2 + m^2} : \text{Electron}$$

$$E = -\sqrt{\mathbf{p}^2 + m^2} : \text{????????}$$



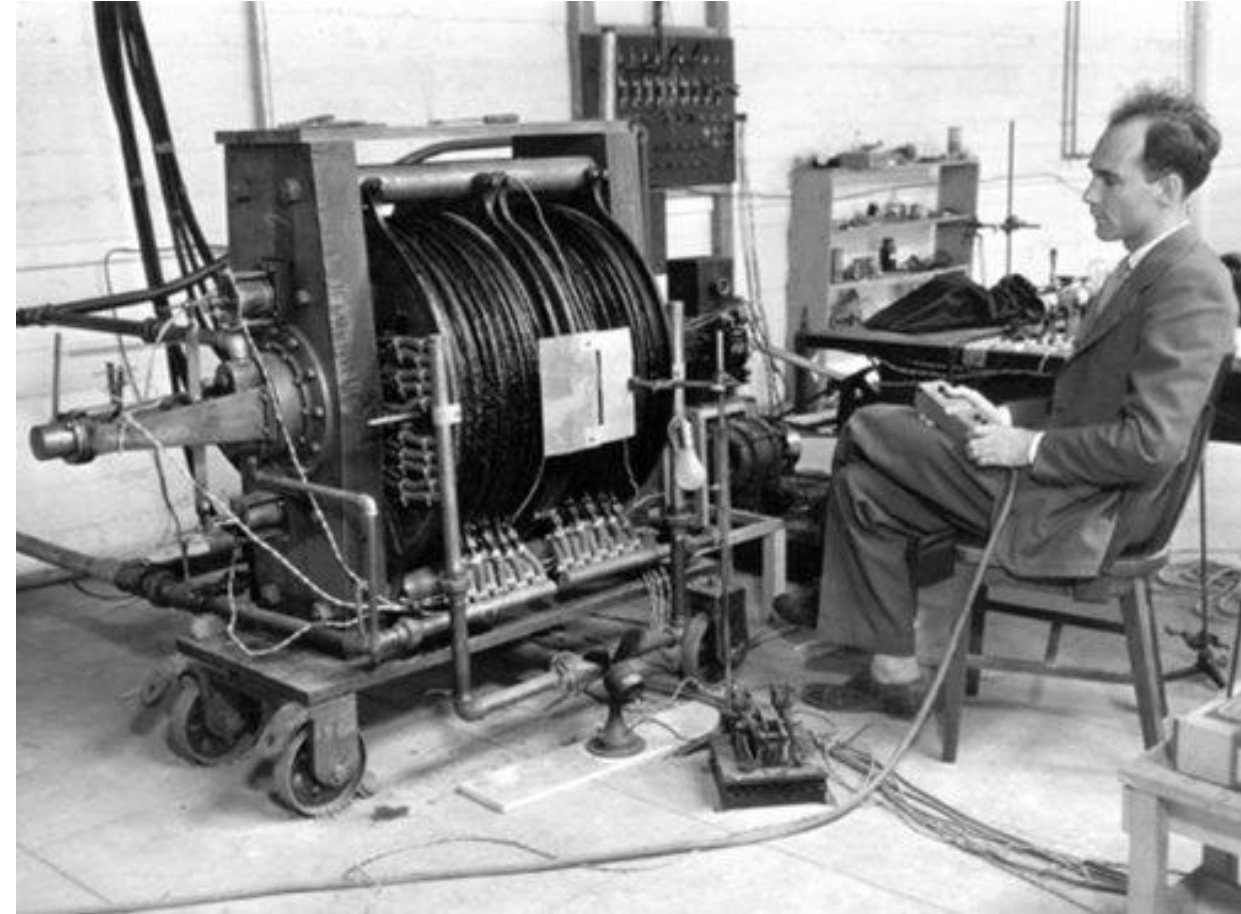
# The Cloud Chamber

- Chamber filled with supersaturated vapor held at a temperature and pressure just above condensation.
- Cosmic rays ionize the chamber along its trajectory.
- The charged particles collect forming condensation areas.
- The mist formed by the condensation creates a “cloud” which can be photographed.



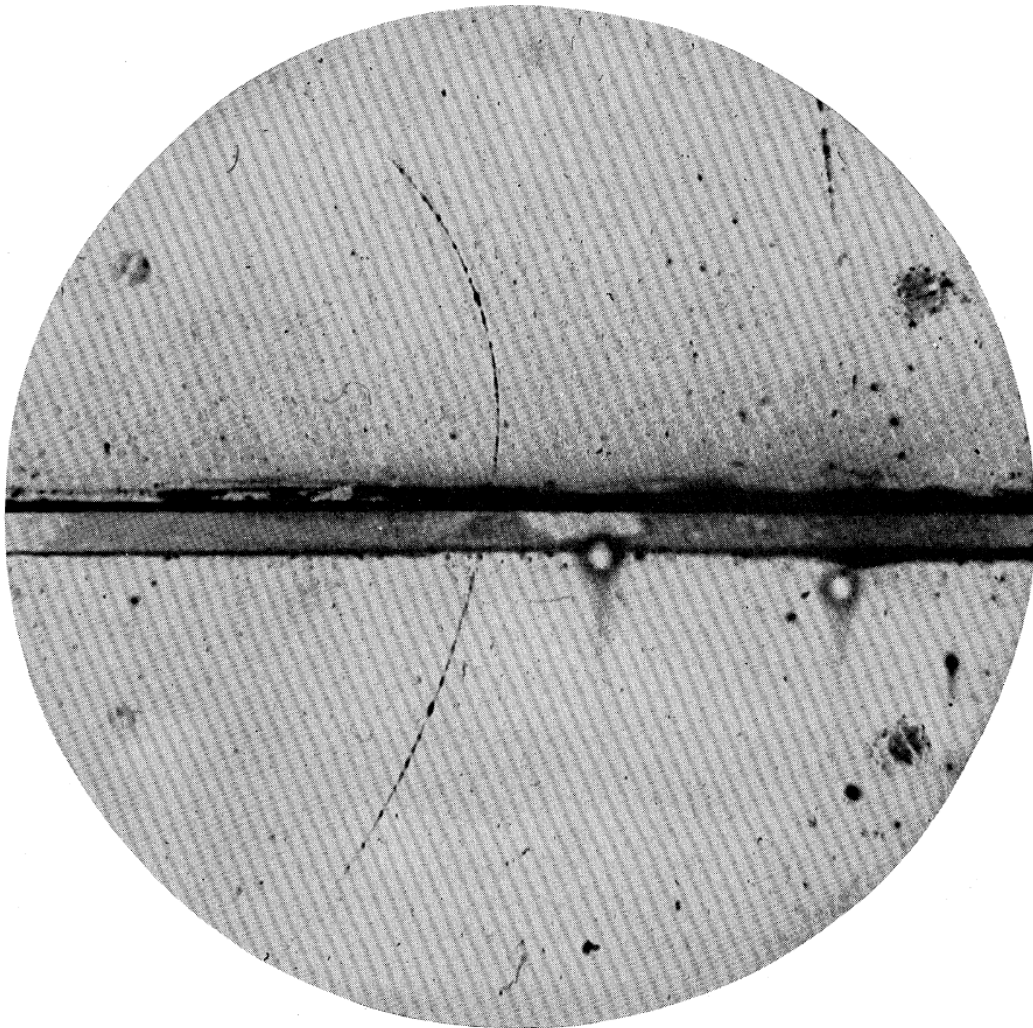
# Carl Anderson and “The Positive Electron”

- Vertical Wilson (cloud) chamber with 1.5 T magnet setup to measure cosmic rays.
- Measurements taken with and without a lead plate in the center of the chamber
- 1300 photographs taken and analyzed. More interesting photographs analyzed “by a whole group of men”





# Results of Anderson's Work



- 15 of 1300 photographs exhibited a positively charged particle lighter than the proton.
- Source of the creating of this particle was still unknown.
- Particle carried no more than twice the charge of a proton and weighed less than 20x that of an electron.

# Cementing Positron's Role in Theory

- Production mechanism of positron was still unknown.
- $\gamma \rightarrow e^+ + e^-$  not possible due to E/p conservation
- Dirac's Proposal:  $\gamma + \gamma \rightarrow e^+ + e^-$  difficult to test in lab
- Blackett & Occhialini Proposal: Same as Dirac with second photon provided by a nearby nucleus
- Positron was finally placed in a complete theory by Feynman in QED and independently Schwinger and Tomonaga
- Many, many, many particle discoveries followed

# References

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