



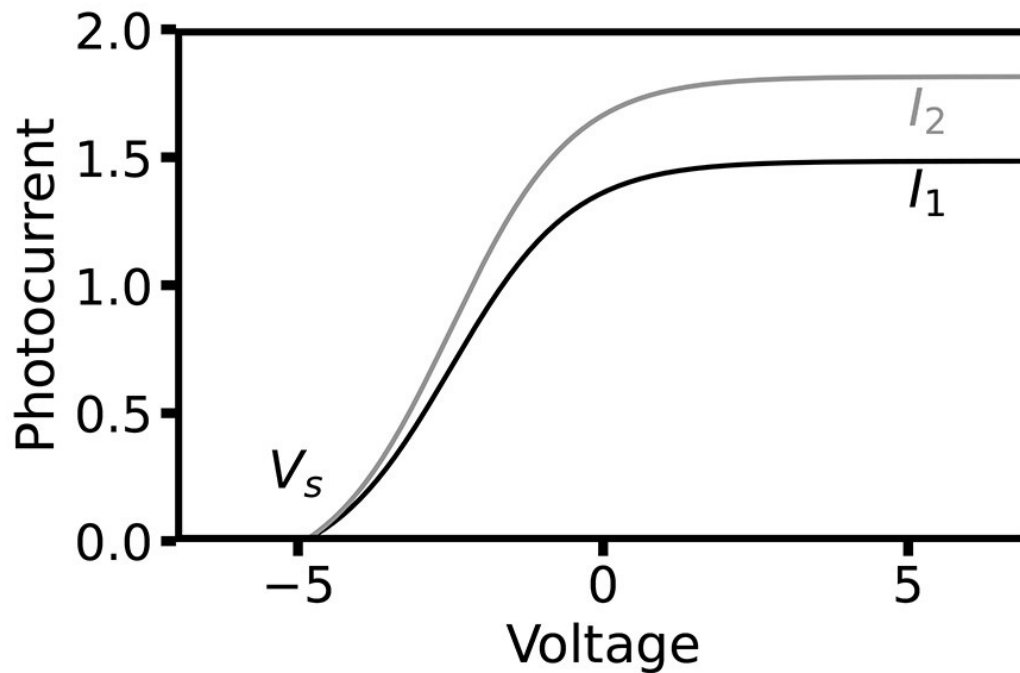
QUANTUM MECHANICS

The photoelectric effect is one of the first experiments taught to quantum students.

It usually is taught incorrectly

Let us understand how to properly use it

Lenard's original experiments (1902)



Lenard had a trigger-mechanism theory for his experiments

Myth #1: A classical model cannot have a frequency threshold for emission of electrons

Fact: Modeling metals by harmonic traps at low energy with a resonant drive after the electron is far enough away has a frequency threshold



For a typical trap of $k=1 \text{ eV/\AA}^2$ one must drive on resonance to reach a separation of 1 nm.

This means no friction.

Electrons are emitted at threshold with low kinetic energy

This idea is consistent with Planck's black body radiation ideas.

Myth #2: Classical models will have long delays for the emission of light

*Fact: Resonant driving requires many oscillations
but the timescales are still short*



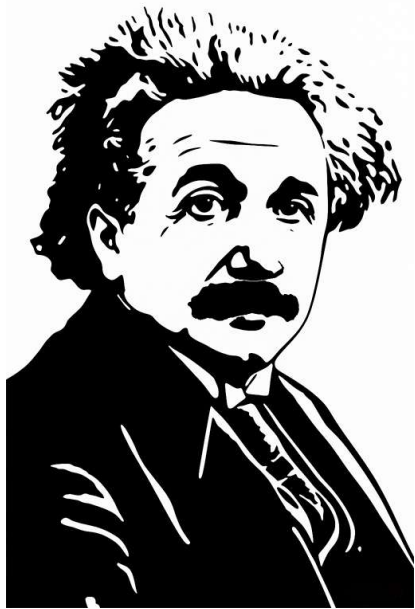
For a typical trap of $k=1 \text{ eV/\AA}^2$, resonant driving requires 10^{11} oscillations.

With an electric field of about 100 V/m , this corresponds to a few μs of delay, which is challenging, but not impossible to measure. It was actually measured to be less than a nanosecond in 1928.

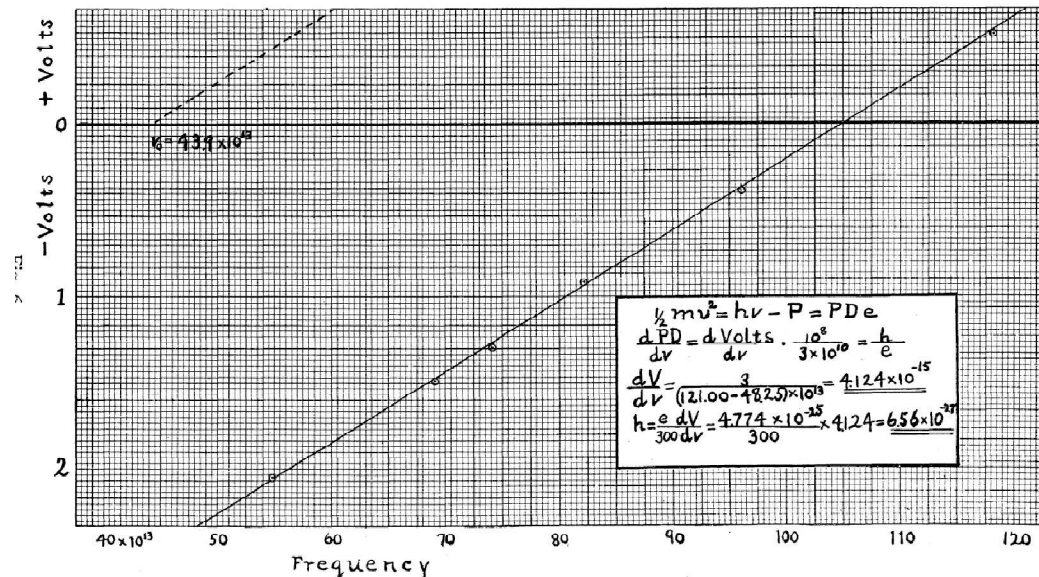
The main problems with the classical model are that the kinetic energy of the electrons will not vary linearly with the photon frequency and the delay times were measured to be less than a nanosecond.

Myth #3: The photoelectric effect proves photons are particles via Einstein's predictions

Fact: The photoelectric effect actually proves that electrons must be quantum mechanical. One can reproduce all of the behavior of the experiment with a classical light field and quantum electrons



1905



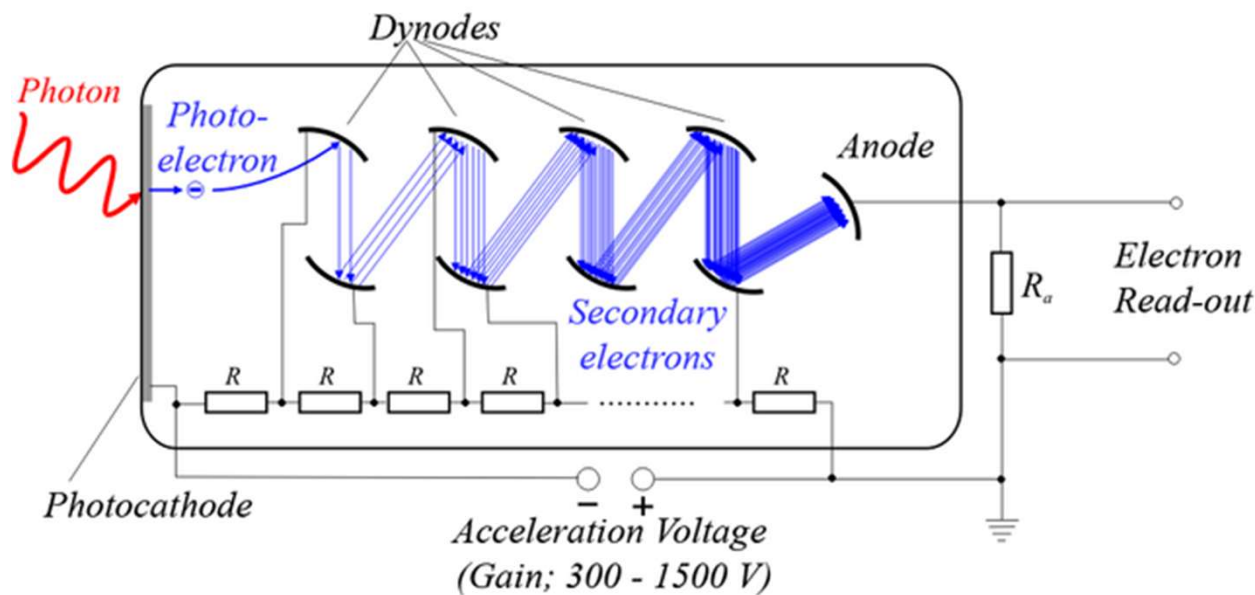
1916

*The photoelectric effect does not prove photons exist,
it instead shows that electrons must be described
quantum-mechanically!*

So, why do we teach the photoelectric effect at all?

Because it does show that if single photons exist, then the photoelectric effect has single-photon sensitivity and can be used to detect them

How to detect single photons



Use the photoelectric effect for single-photon sensitivity

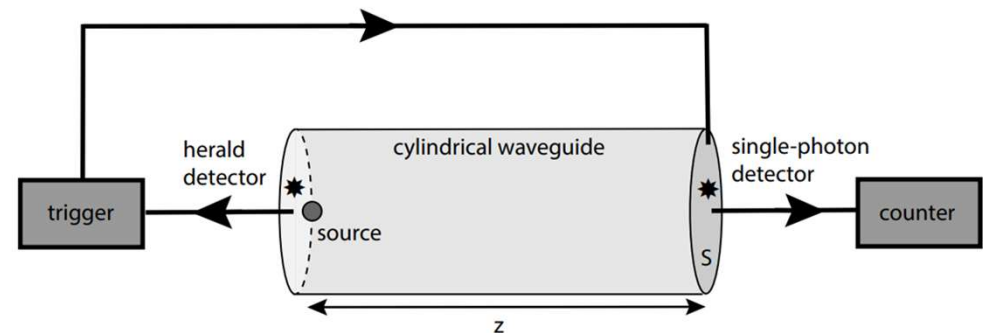
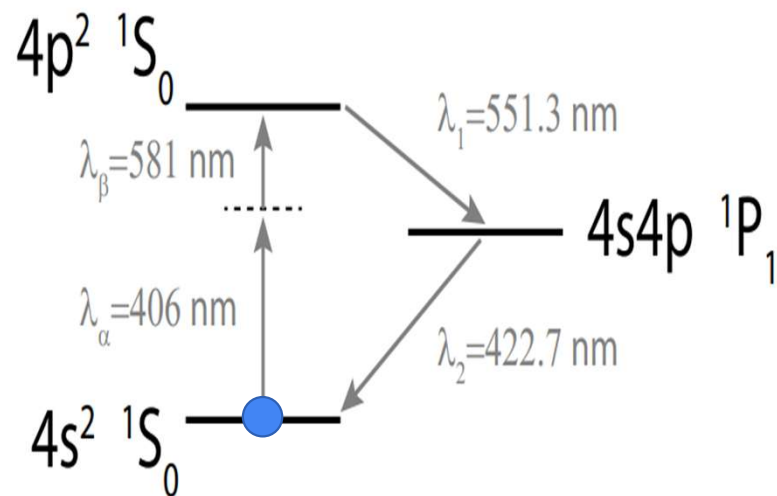
Amplify the single emitted electron many-fold to make a large enough current pulse it can be measured with classical equipment

Reset to measure again after the event is recorded

*A single photon can be imaged with a
PMT once and only once!!*

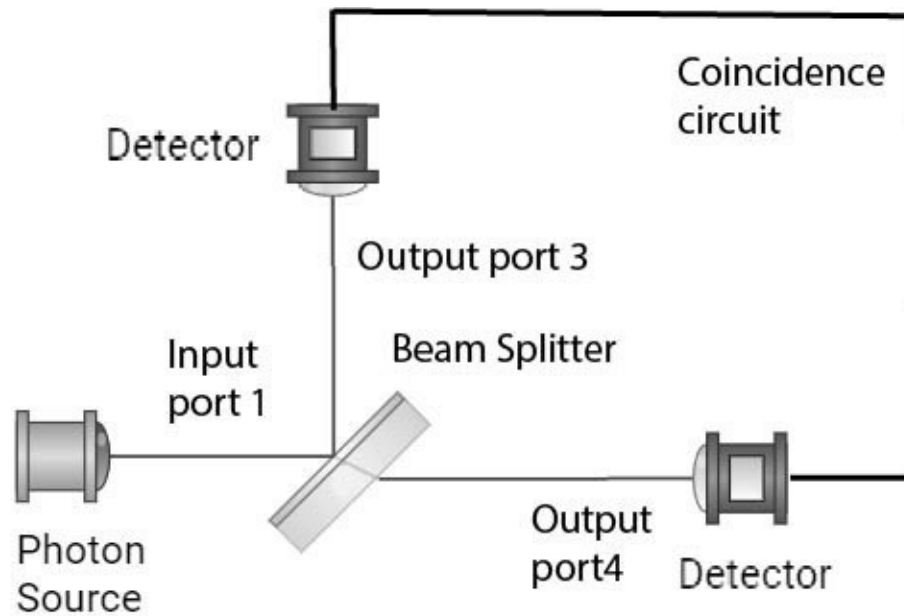
Because it is destroyed upon detection.

Calcium cascade single photon source \approx 1980

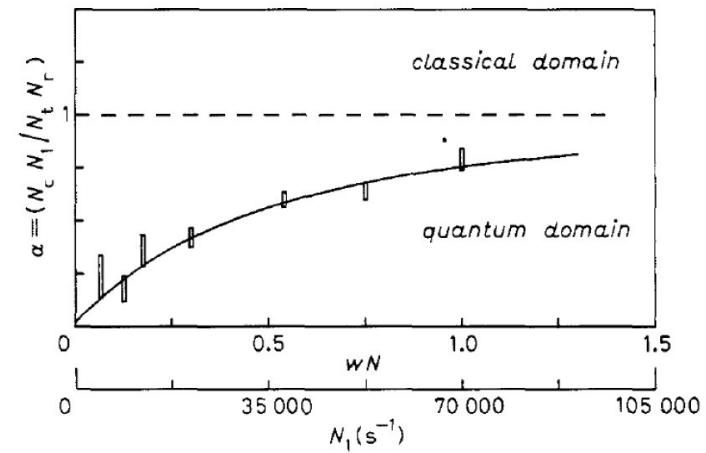
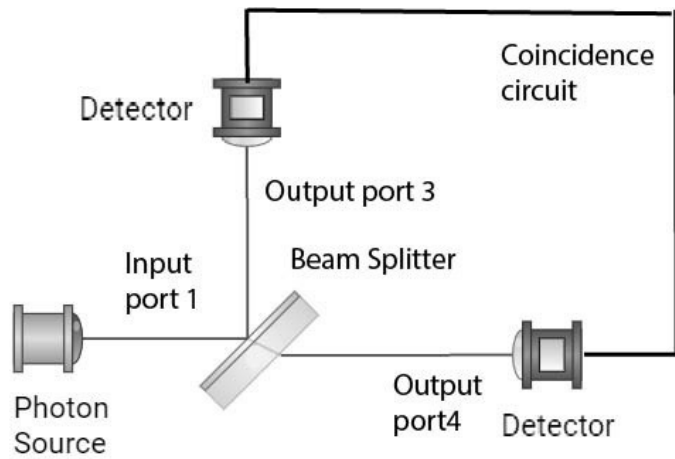


This is a heralded single-photon light source

G2 experiment



G2 experiment



Single photons are complicated to make. They do not just come from dimming classical light

*The most important property is they
can be measured (destructively) once
and only once*

*Please don't just call them particles of
light*

Thanks to



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