

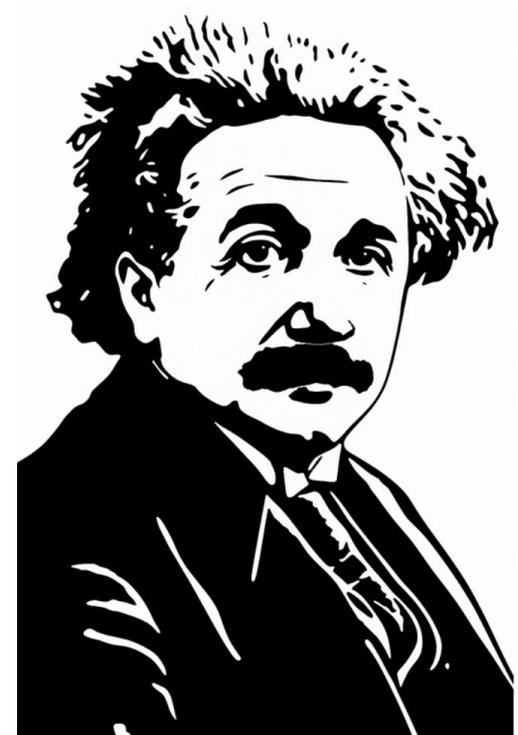
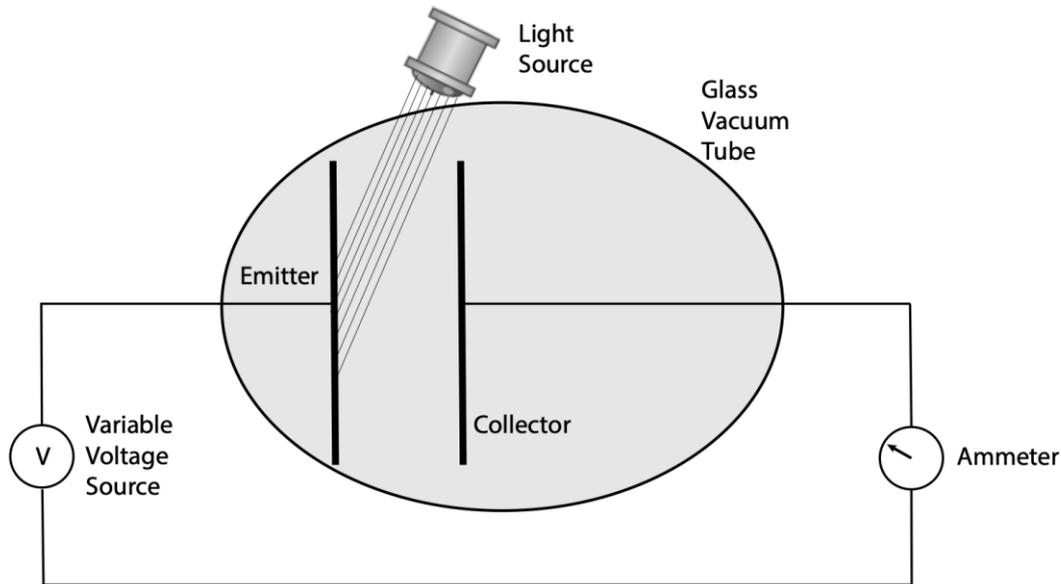
Teaching about single photons in a modern physics class

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Photoelectric effect experiment

Typically used to introduce the photon model of light in modern physics courses after first discussing the shortcomings of the classical model in explaining experimental observations



Photoelectric effect experiment

But in the 1960's, it was shown that the experimental results can be obtained by treating the electromagnetic field classically and the electrons quantum mechanically.

“It is an historical accident that the photon concept should have acquired its strongest early support from Einstein’s considerations on the photoelectric effect”

(Lamb & Scully, 1968)

Single-photon experiments

Can help answer the question: “What is a photon?”

Can examine photon properties such as **it can be measured once and only once**

Photoelectric effect leads to critically important technology – it can be used to detect individual photons

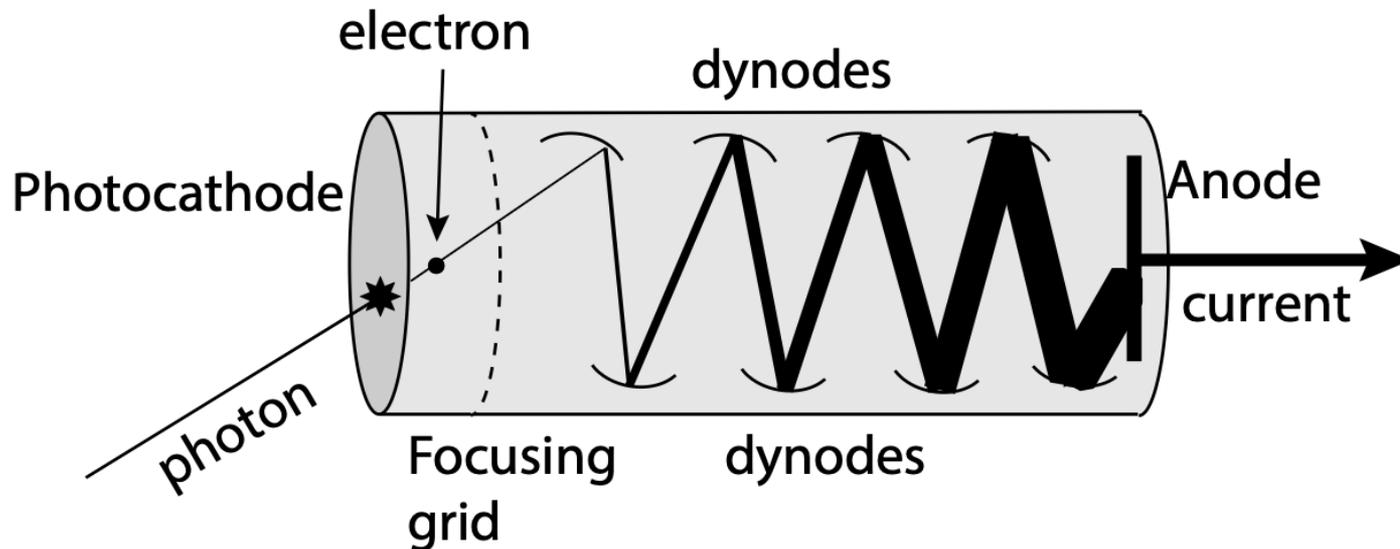
Single-photon detection

The photocathode metal is struck by a photon and emits an electron.

Electrons are focused onto them with enough energy that they will emit two to three electrons for each electron that hits it (~ 30 stages).

The cascade ends with a sizable current that can be measured using classical equipment.

Photomultiplier tube

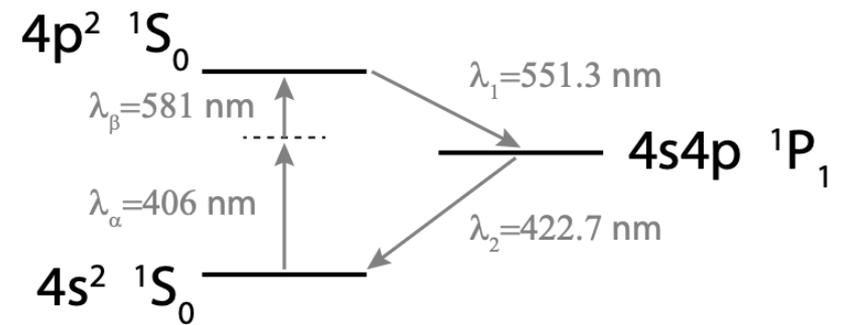
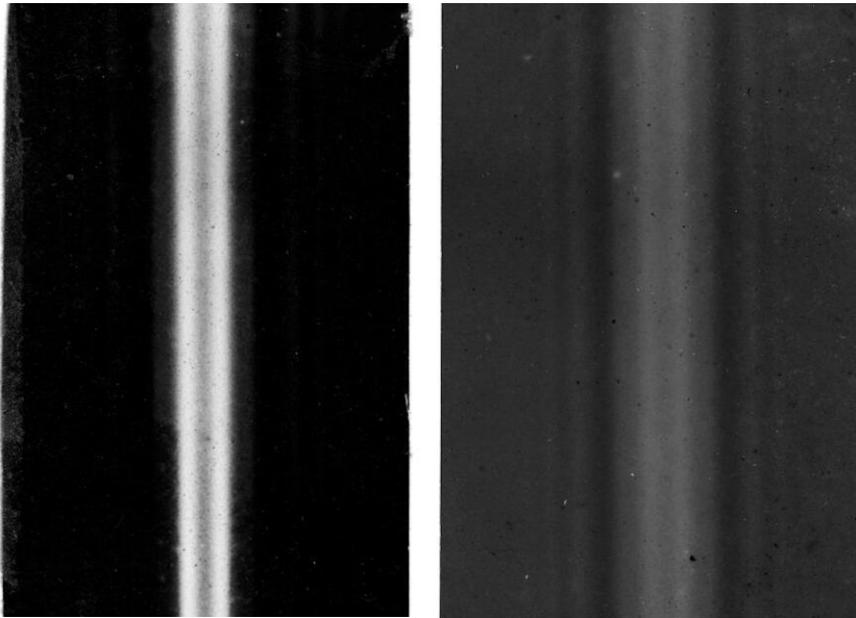


Single-photon sources

Dim Light

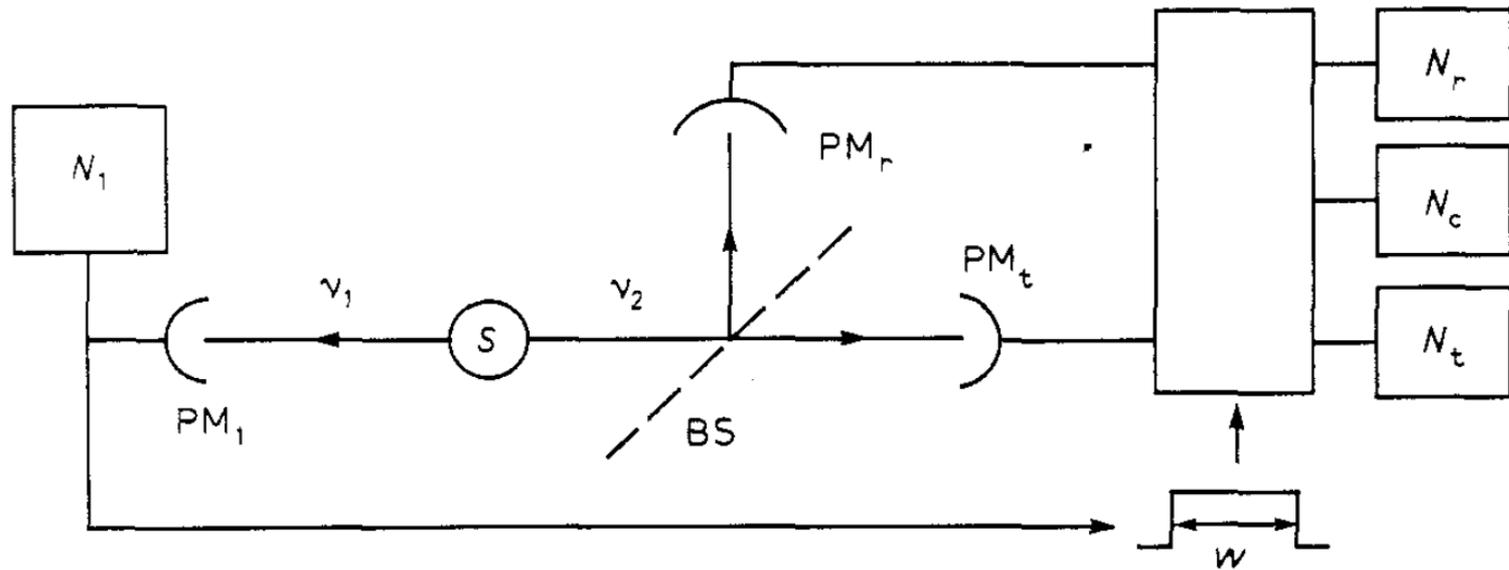
vs.

Calcium Cascade



G2 Experiment

Grangier, Roger & Aspect (1986)



G2 Experiment

N_H = number of heralded photons

N_r = number of reflected path detector counts

N_t = number of transmitted path detector counts

N_C = number of measured coincidences

Anticorrelation parameter:
$$\alpha = \frac{P_C}{P_r P_t} = \frac{N_C N_H}{N_r N_t}$$

G2 Experiment

$$\alpha = \frac{P_C}{P_r P_t} = \frac{N_C N_H}{N_r N_t}$$

Dim Light

vs.

Calcium Cascade

$$\alpha = 1.05$$

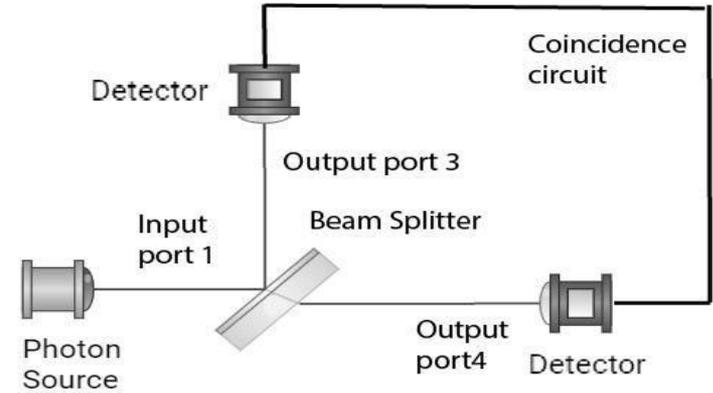
$$\alpha = 0.05$$

Number of heralded photons as the counts in a time interval that goes straight to a detector from the source, with no beam splitter.

Not zero due to PMT dark counts and possibility of two atoms emitting photons within the same measurement window

G2 Experiment Class Worksheet

Data from Aspect & Grangier (1987)

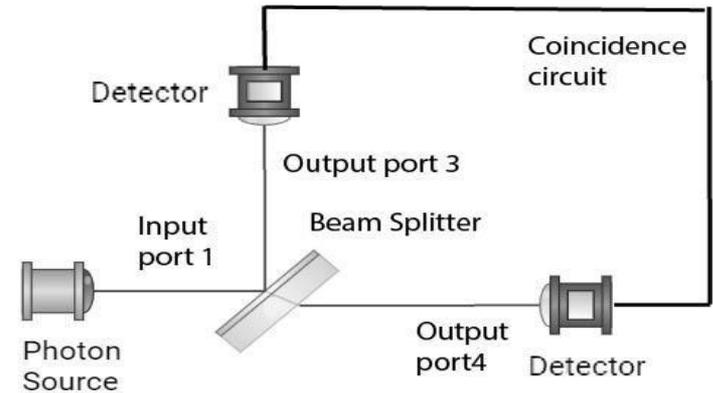


Set 1: Dim LED Light Source				
Experiment	Number of Input Photons	Single PMT 3 Counts	Single PMT 4 Counts	Calculated Coincidence Counts
1	148,512,000	94,224	117,312	75
2	457,000,000	337,920	423,680	313
3	955,040,000	832,840	913,680	794

Set 2: Radiative Calcium Cascade Source				
Experiment	Heralded Photon Counts	Single PMT 3 Counts	Single PMT 4 Counts	Calculated Coincidence Counts
1	152,564,000	78,260	98,900	51
2	391,680,000	241,920	326,400	202
3	422,520,000	399,840	519,960	492

G2 Experiment Class Worksheet

Data from Aspect & Grangier (1987)



Experiment	Calculated Coincidence Counts	Measured Coincidence Counts	GR Coefficient, α
Set 1, Experiment 1	75	82	1.09
Set 1, Experiment 2	313	329	1.05
Set 1, Experiment 3	794	840	1.06
Set 2, Experiment 1	51	9	0.18
Set 2, Experiment 2	202	86	0.43
Set 2, Experiment 3	492	314	0.64

G2 Experiment Class Worksheet

Deep Dive:

Since the 1980s, better ways of making heralded and unheralded single-photon sources have been created, and we are getting close to having single photons available on demand. That would mean pushing a button, and a photon comes out. Go and research what these modern sources are and see if you can predict how soon we will have single photons on demand. Terms to look for include “parametric down conversion” and “quantum dot single-photon sources.”

Thank you!

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