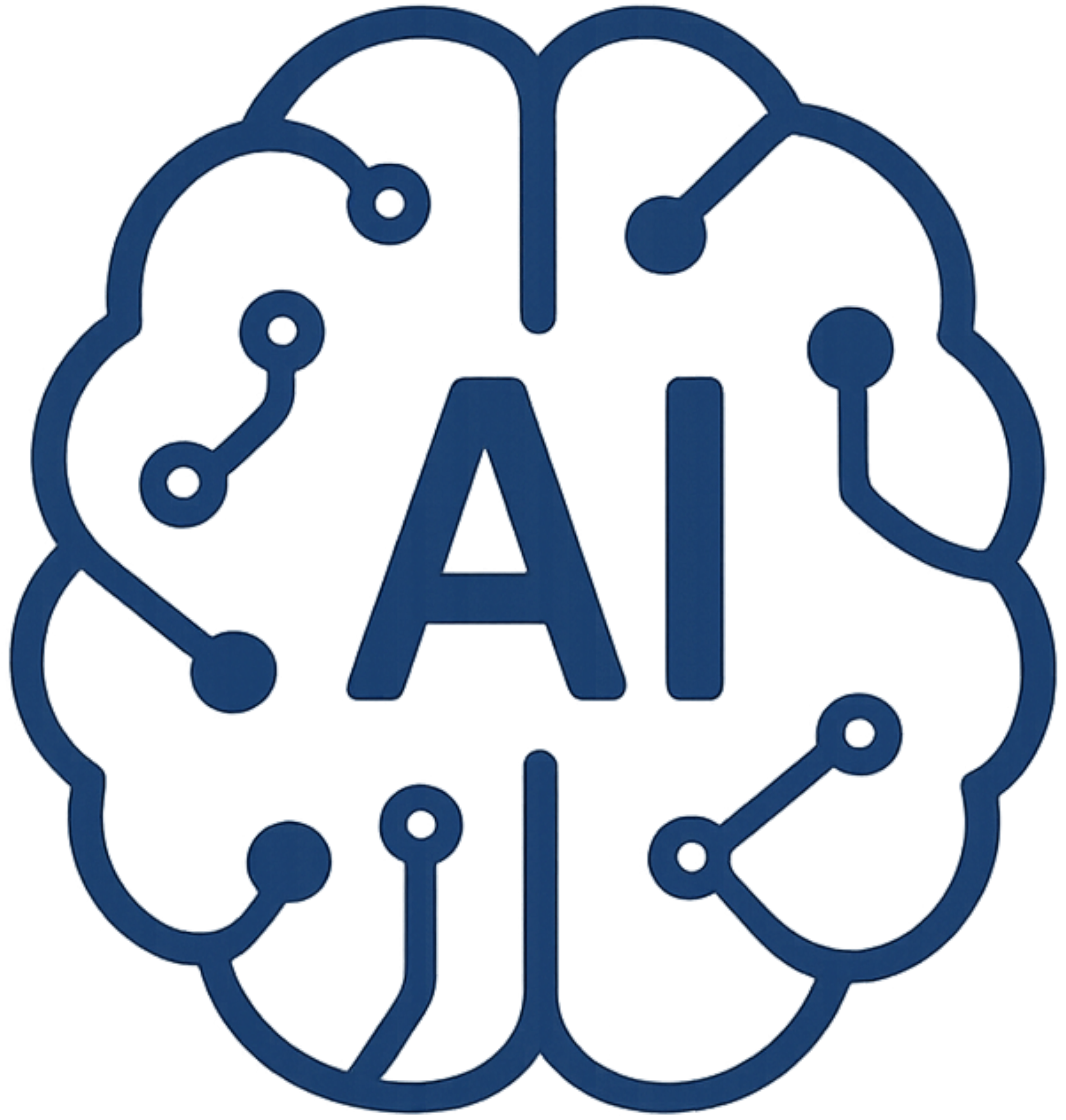
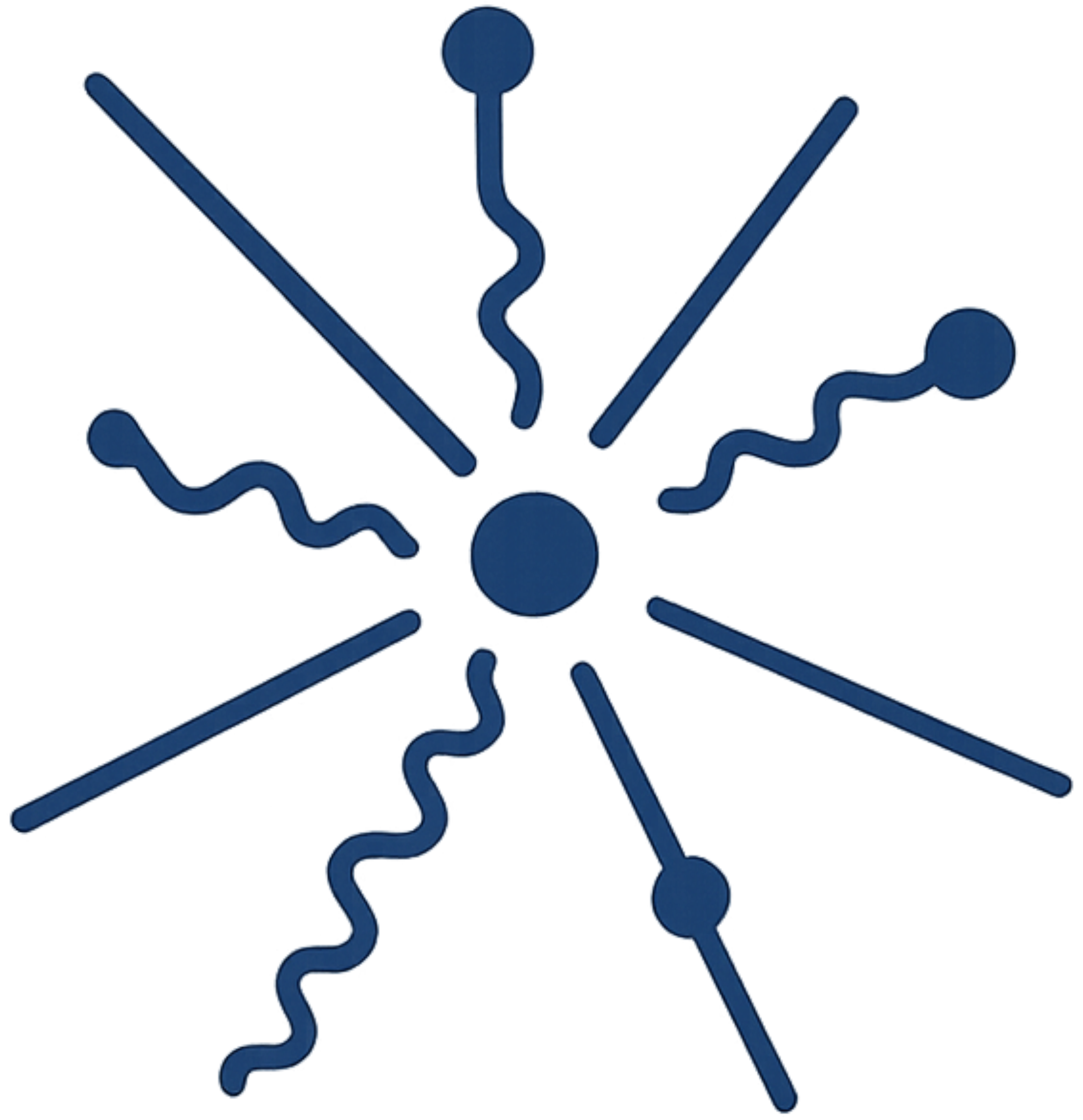
Introduction to

AI-Driven HEP

S. A. Fard - School of Physics (IPM)





Session 3

Instrument

Grupen, Claus, and Boris Shwartz. Particle detectors. Cambridge university press, 2008.

Ade, Peter AR, Matthew J. Griffin, and Carole E. Tucker. Physical principles of astronomical instrumentation. CRC Press, 2021.

Karttunen, Hannu, et al., eds. Fundamental astronomy. Berlin, Heidelberg: Springer Berlin Heidelberg, 2007.

Instrument starts with Interaction & medium

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Every interaction process can be used
as a basis for a detector concept

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The main interactions

Ionisation , Excitation, Bremsstrahlung

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Photon

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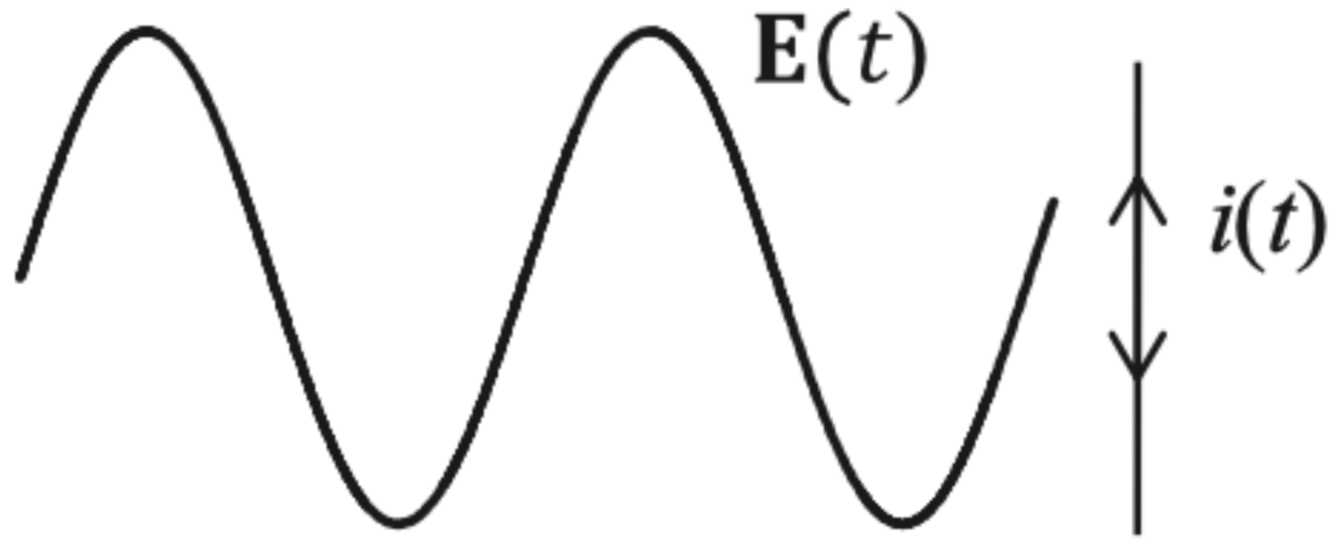
Photon - Neutrino

Radio Photon

$E \sim 10^{-3}$ eV and $\lambda \sim 1$ mm



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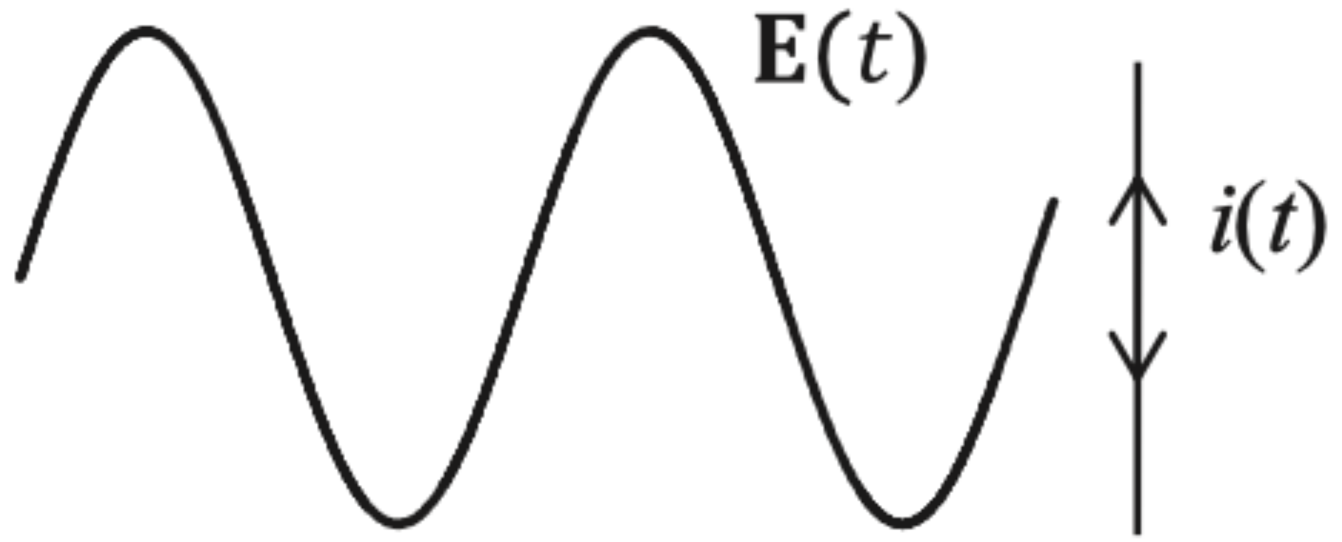

Conducting material (metal)

Plasma (Earth's ionosphere)

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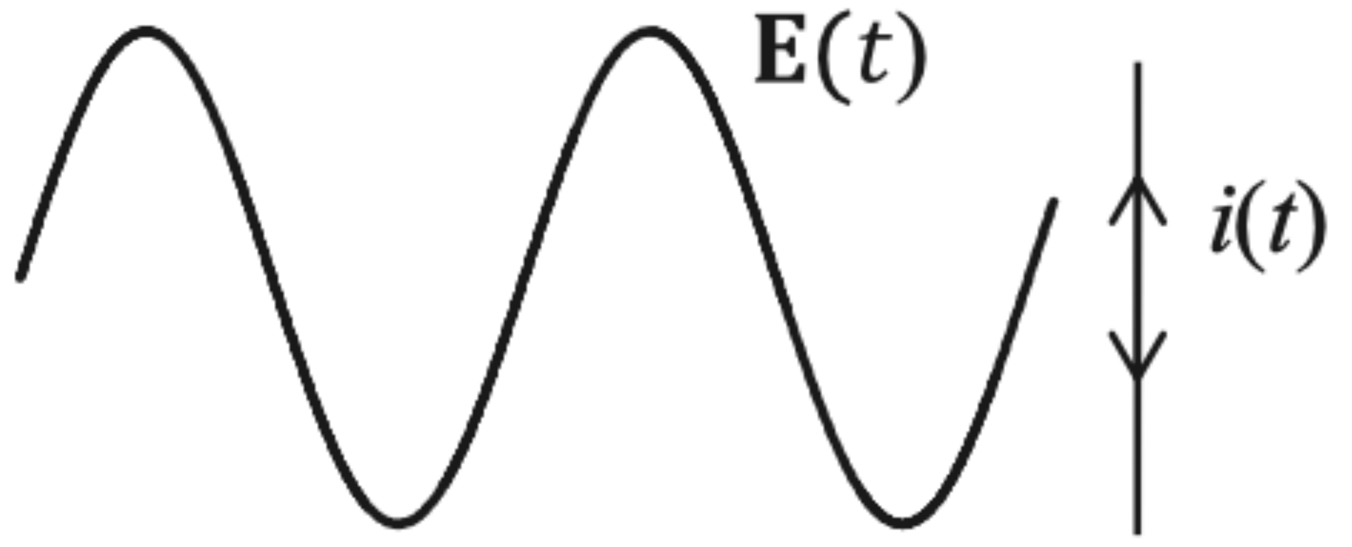


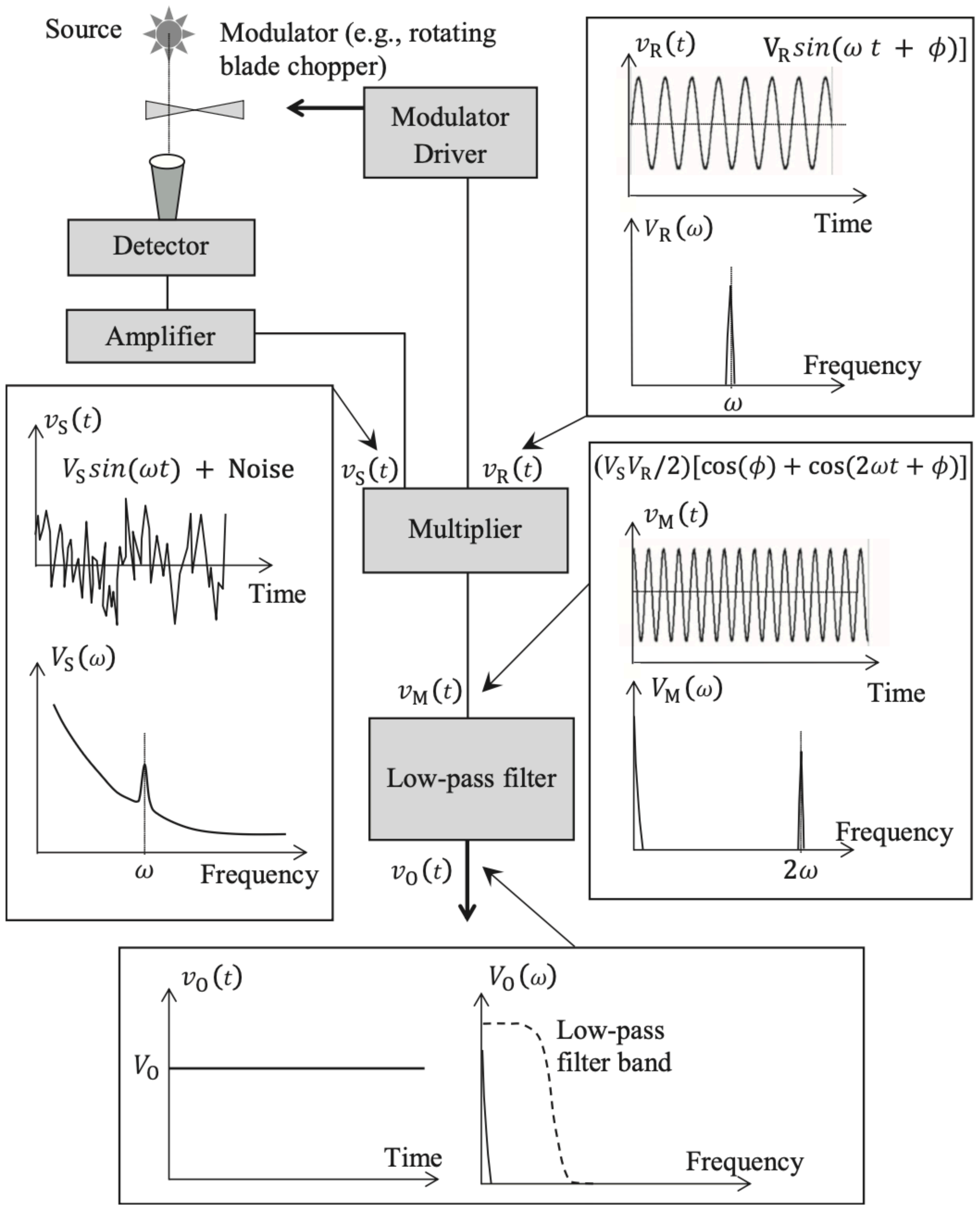
Ground-based radio astronomy observations are not possible at wavelengths longer than Earth's ionosphere plasma wavelength ~24 m (frequency ~13 MHz)

$$\nu_p \sim 9\sqrt{n_e}$$

(In)Coherent detection

Coherent:

measuring both the amplitude and phase of an incoming flux (e.g. EM radio or microwaves).



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As the wavelength decreases:

The oscillation frequency becomes extremely high, keeping track of the phase precisely becomes technically very difficult.

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Incoherent (direct) detection: the detector simply measures the intensity (power) of the incoming flux, ignoring phase.

In this regime, the concept of the wave is less convenient.

IR-Optical-UV

$E \sim 1$ eV to 10 eV

Absorption of photon

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- Bolometric detector : measurable rise in temperature of resistive material
- Photodetector : charge carriers that can move under the influence of an electric field

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IR-Optical-UV

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Bolometric detector : measurable rise in temperature of resistive material

Photodetector : charge carriers that can move under the influence of an electric field

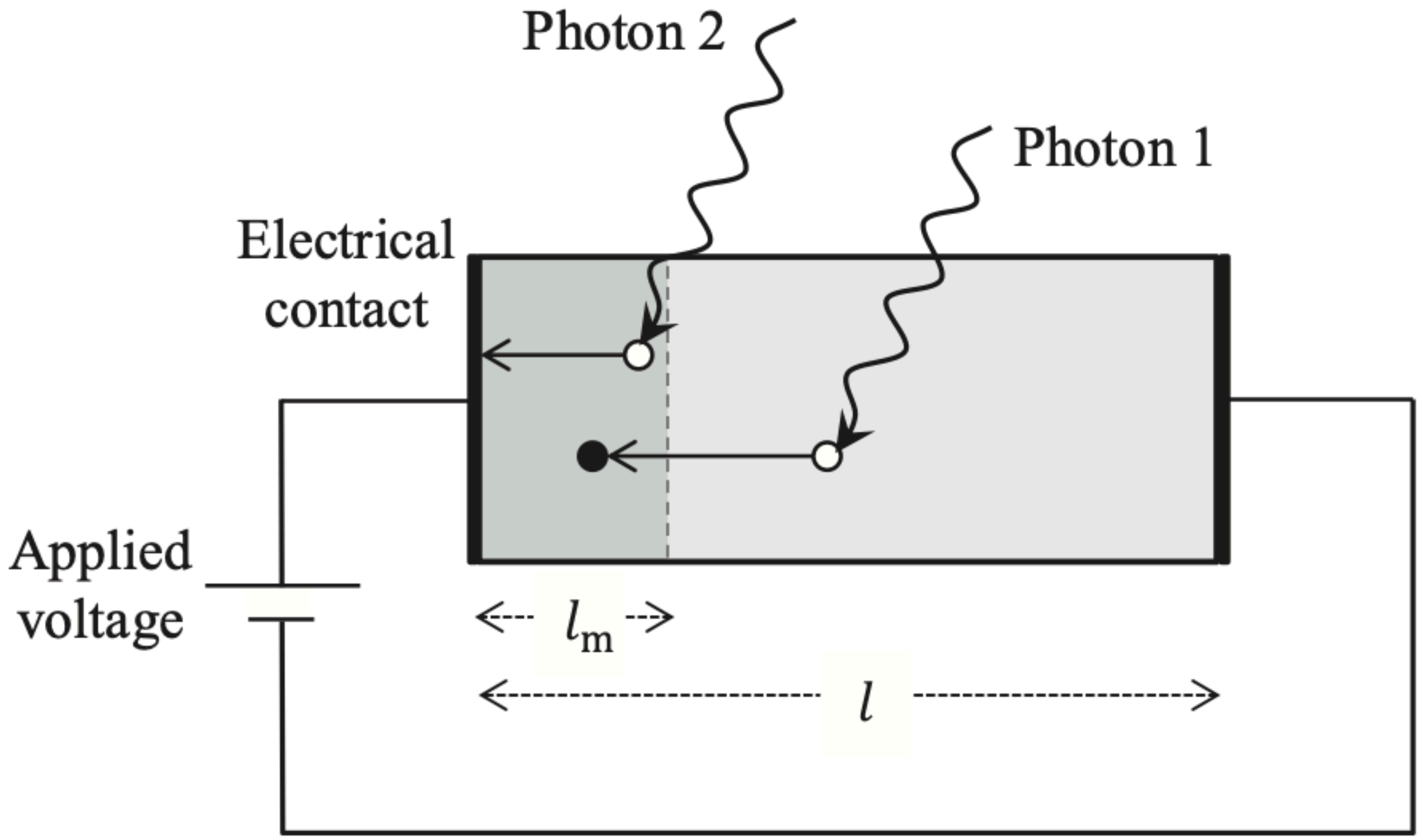
Energy Gaps at 300 K and Corresponding Cut-Off Wavelengths for Some Semiconductor Materials

Material	ΔE (eV)		λ_c (μm)	
	300 K	77 K	300 K	77 K
Si	1.12	1.16	1.11	1.07
Ge	0.66	0.73	1.88	1.69
InSb	0.17	0.23	7.19	5.31
GaAs	1.42	1.51	0.87	0.82
InP	1.35	1.41	0.92	0.88

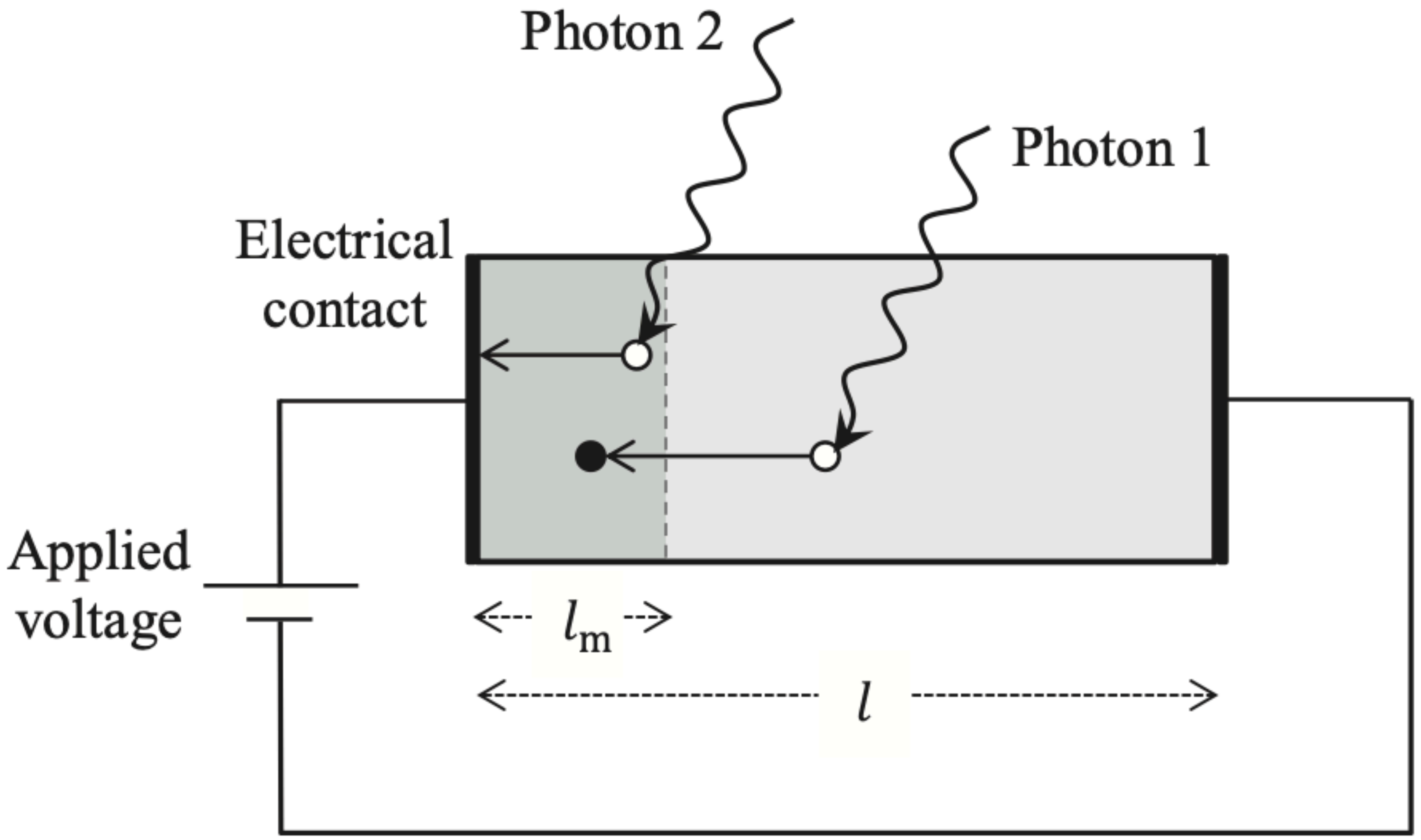
Source: Data from Siklitsky & Tolmatchev (2019).

InSb (Indium Antimonide) InP (Indium Phosphide), GaAs (Gallium Arsenide),

Photodetector



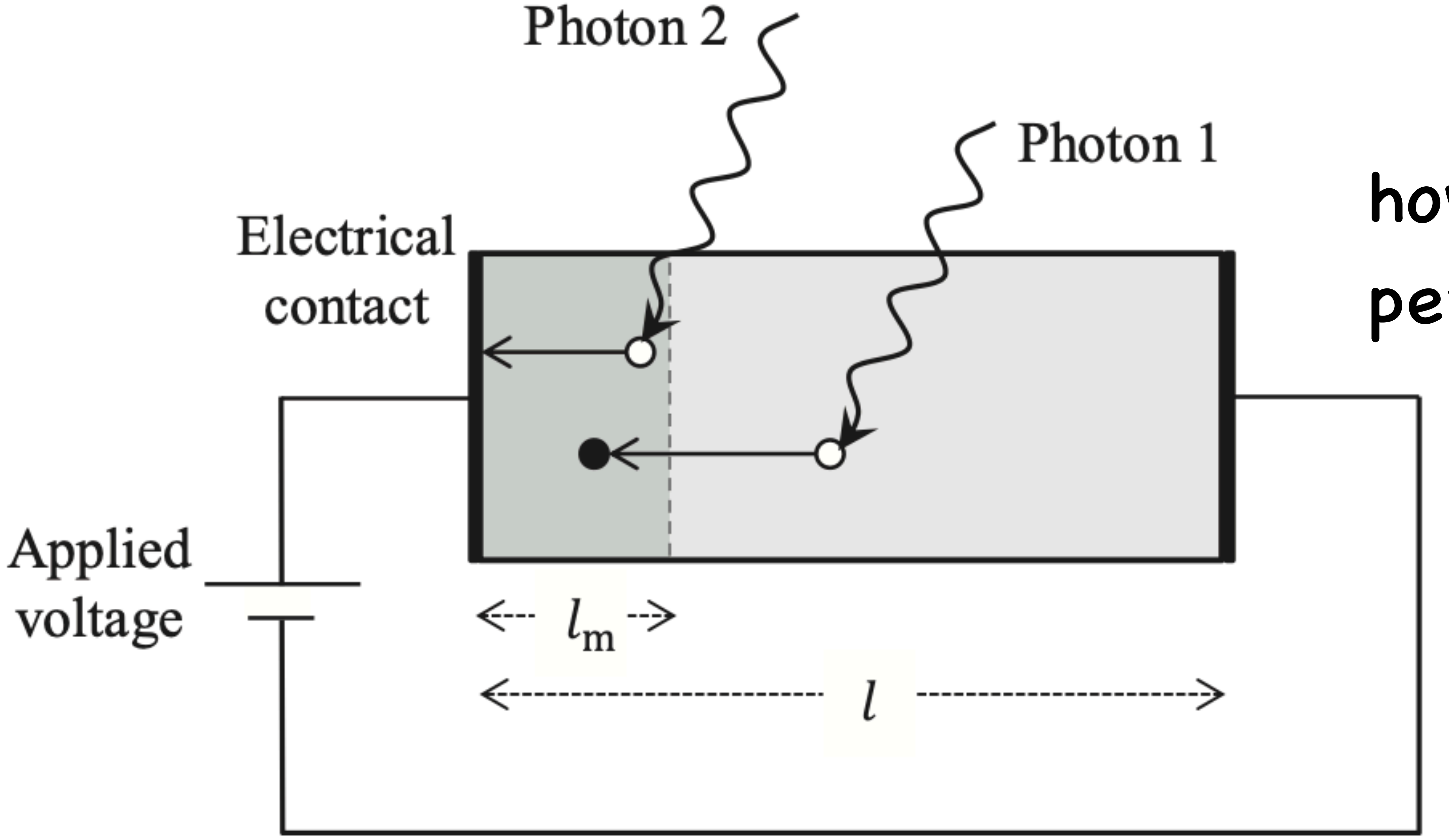
Photodetector



Detector Responsivity

$$S = \eta_d g \frac{e\lambda}{hc} \Delta\nu.$$

Photodetector



how much current the detector produces per unit of incident power

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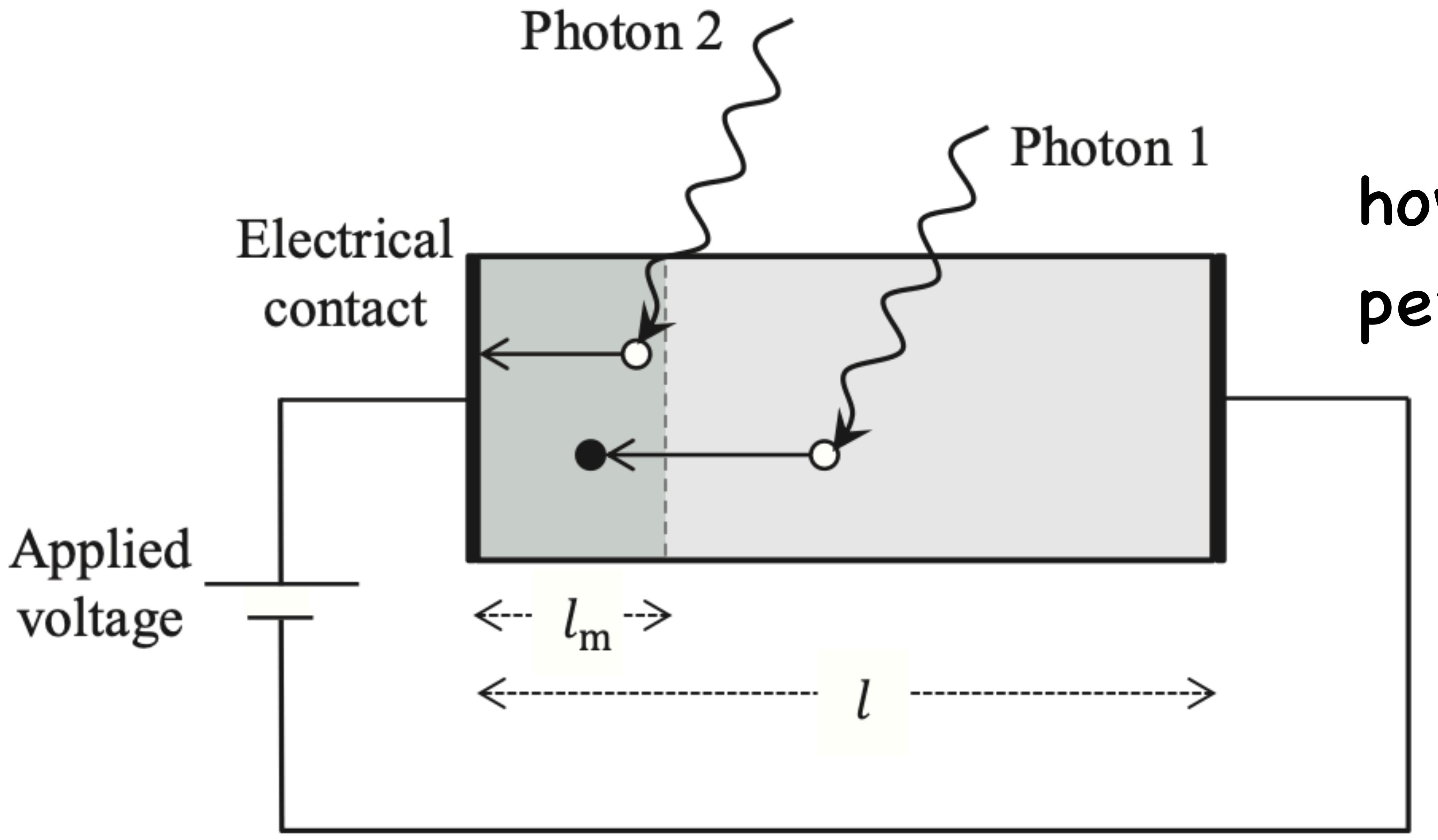


how much current the detector produces per unit of incident power

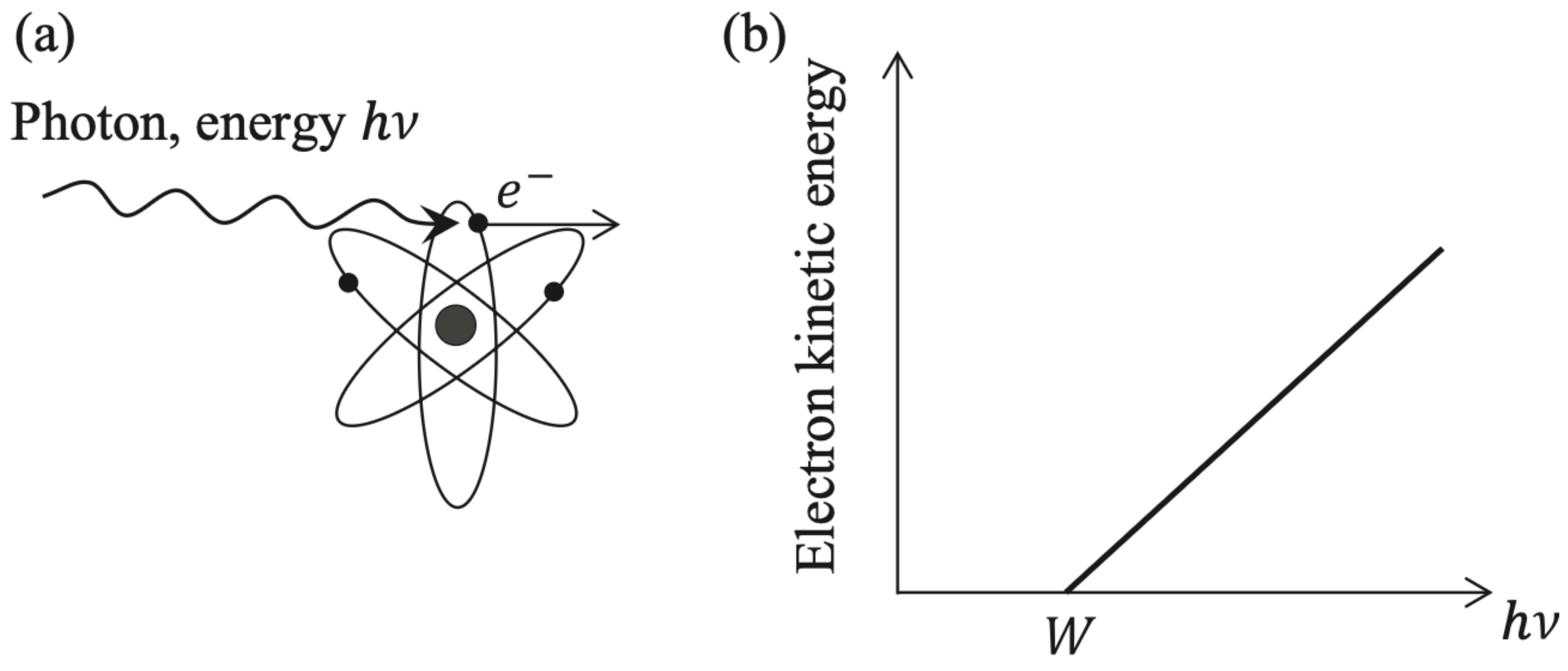
η_d : probability that a single incident photon will liberate an electron

Detector Responsivity

$$S = \eta_d g \frac{e\lambda}{hc} \Delta\nu.$$

g : photoconductive gain, depends on the properties of the material and the magnitude of the applied electric field.

Photoelectric effect



The emission of electrons from metal when it is exposed to light of sufficient frequency

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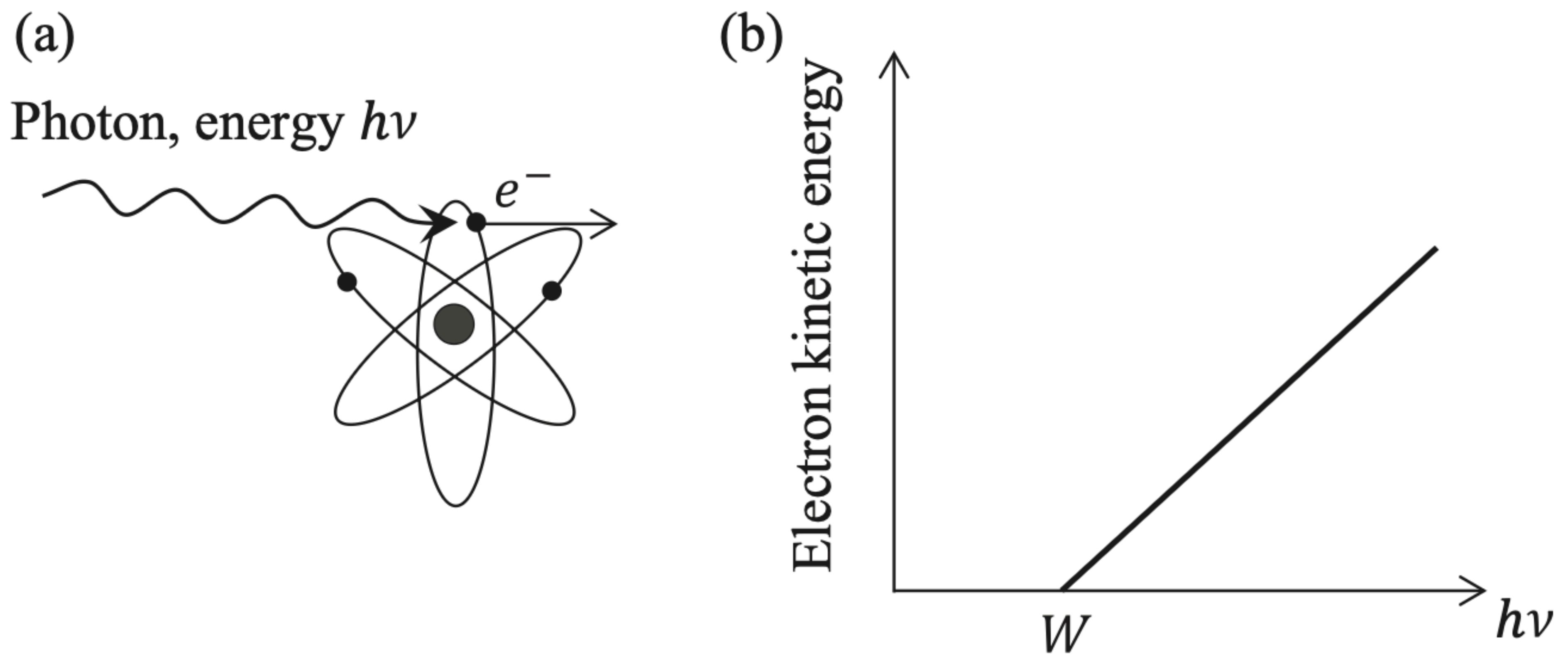

$K_{max} = h\nu - W$

the maximum kinetic energy of emitted electrons

W is material's work function

The emission of electrons from metal when it is exposed to light of sufficient frequency

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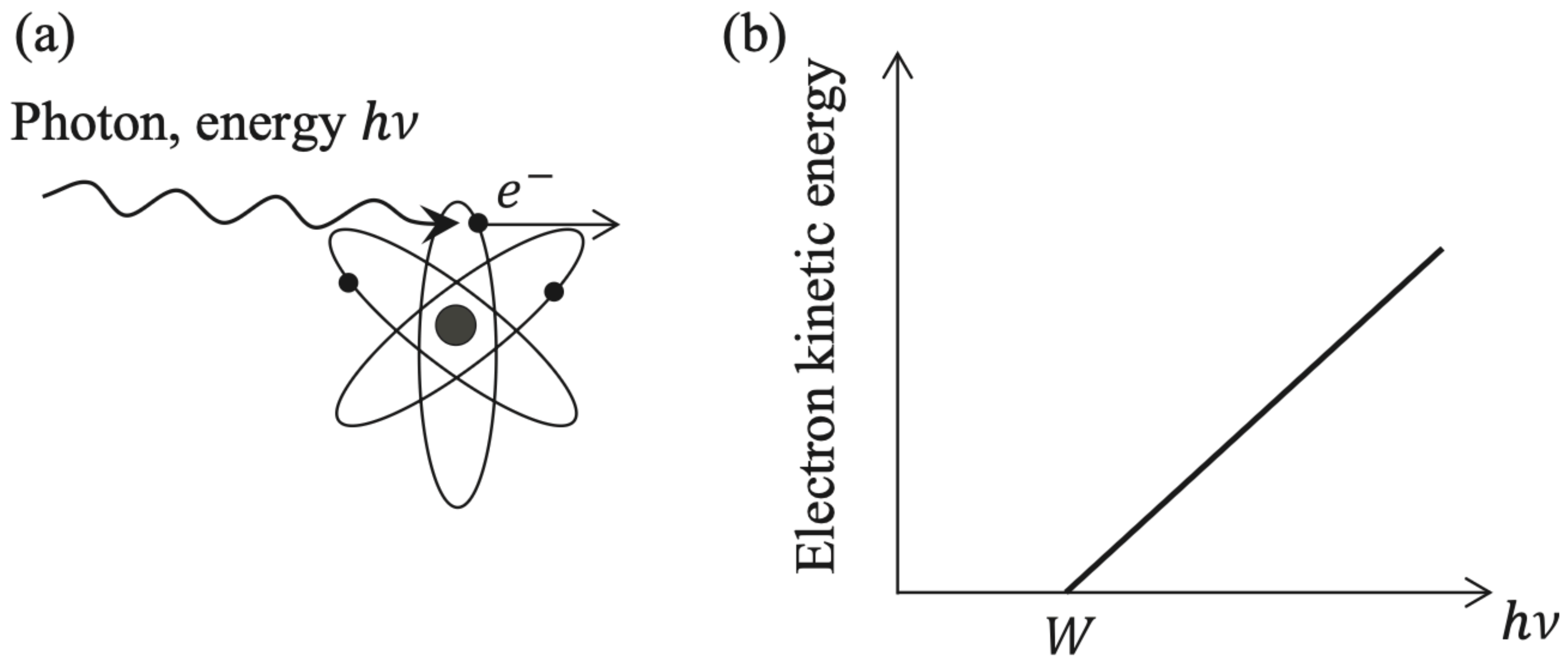

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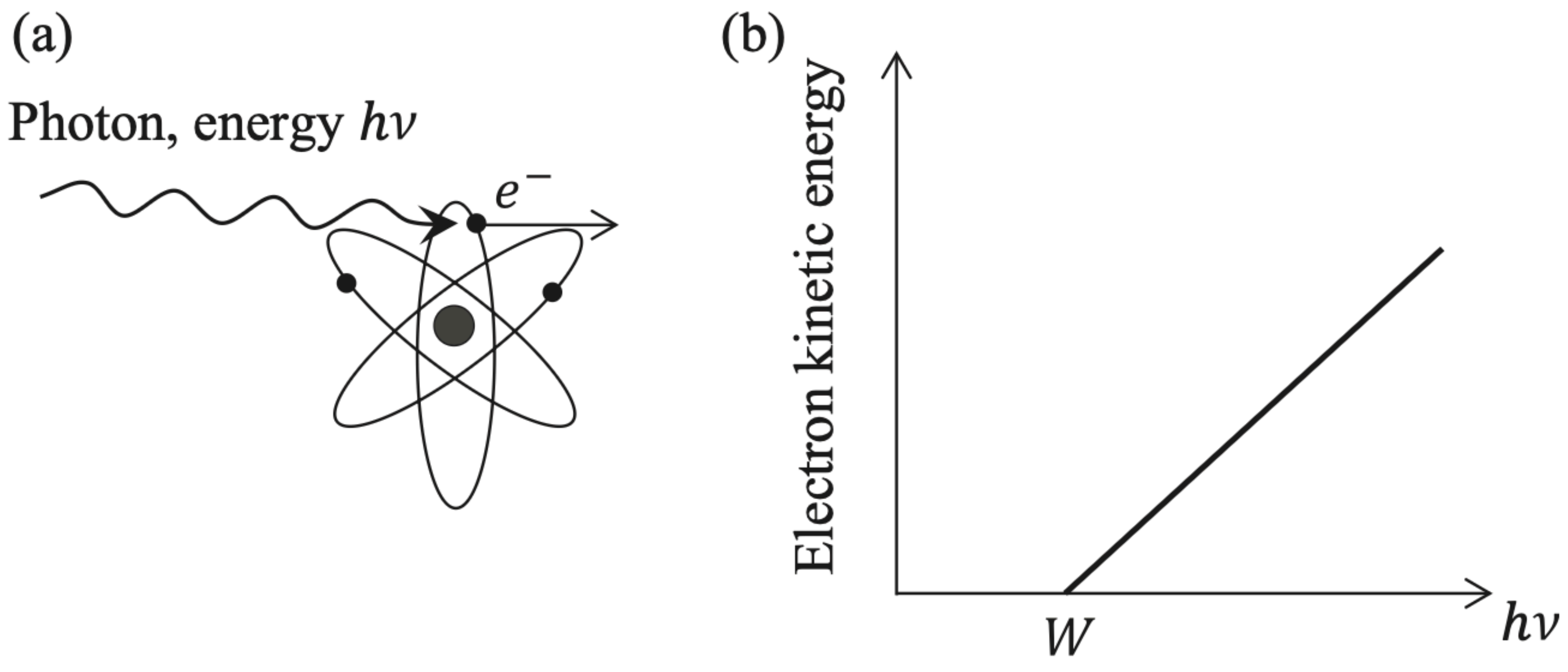
The emission of electrons from metal when it is exposed to light of sufficient frequency

The interaction probability per unit mass is roughly proportional to $Z^5/E^{7/2}$

E is the photon energy (must be at least as great as the work function)

Z is the atomic number of the material

Photoelectric effect



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High-Z materials are much more efficient absorbers, The absorption probability declines rapidly with increasing photon energy

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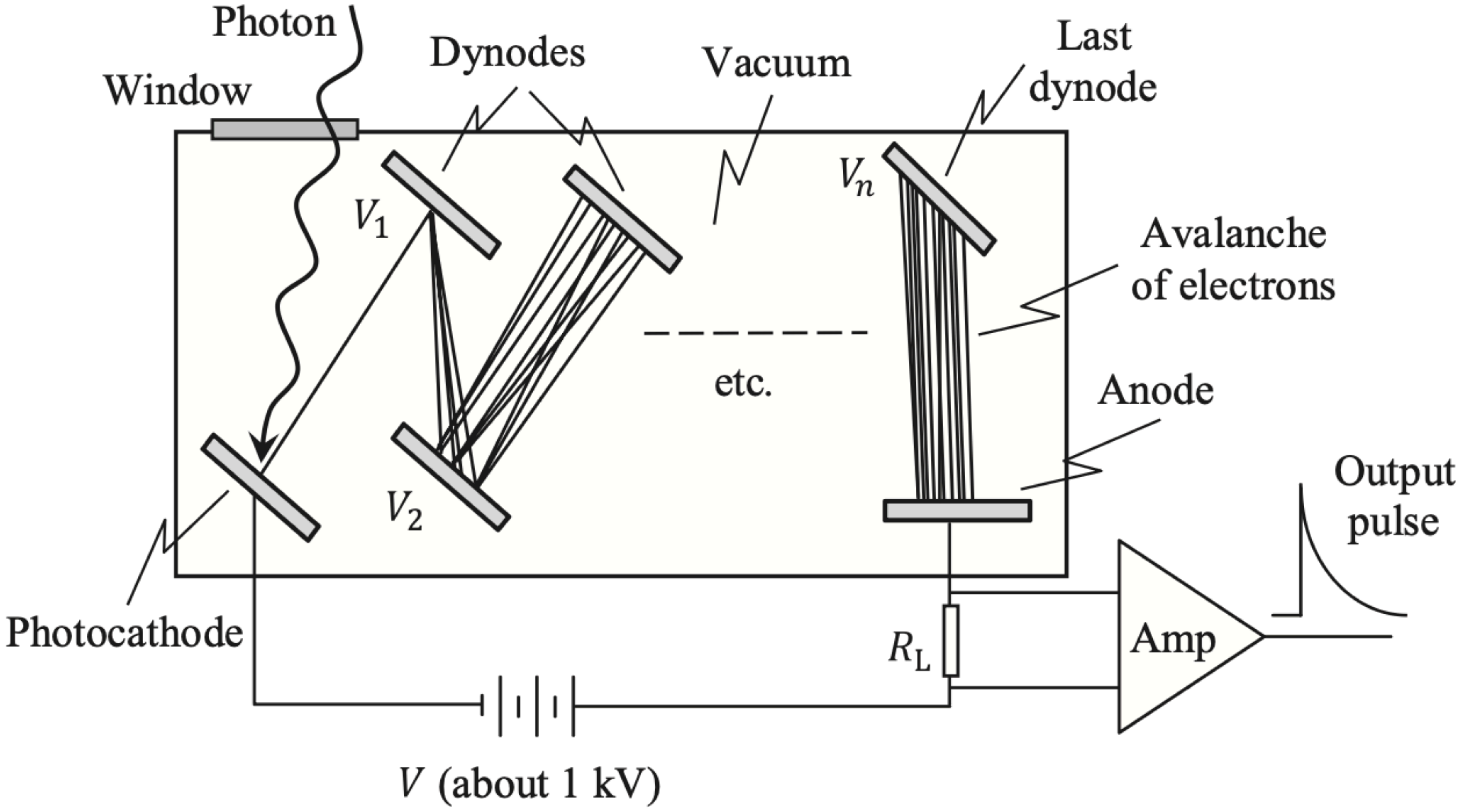
PhotoMultiplier Tube (PMT)



converts a low-intensity light signal to a current signal

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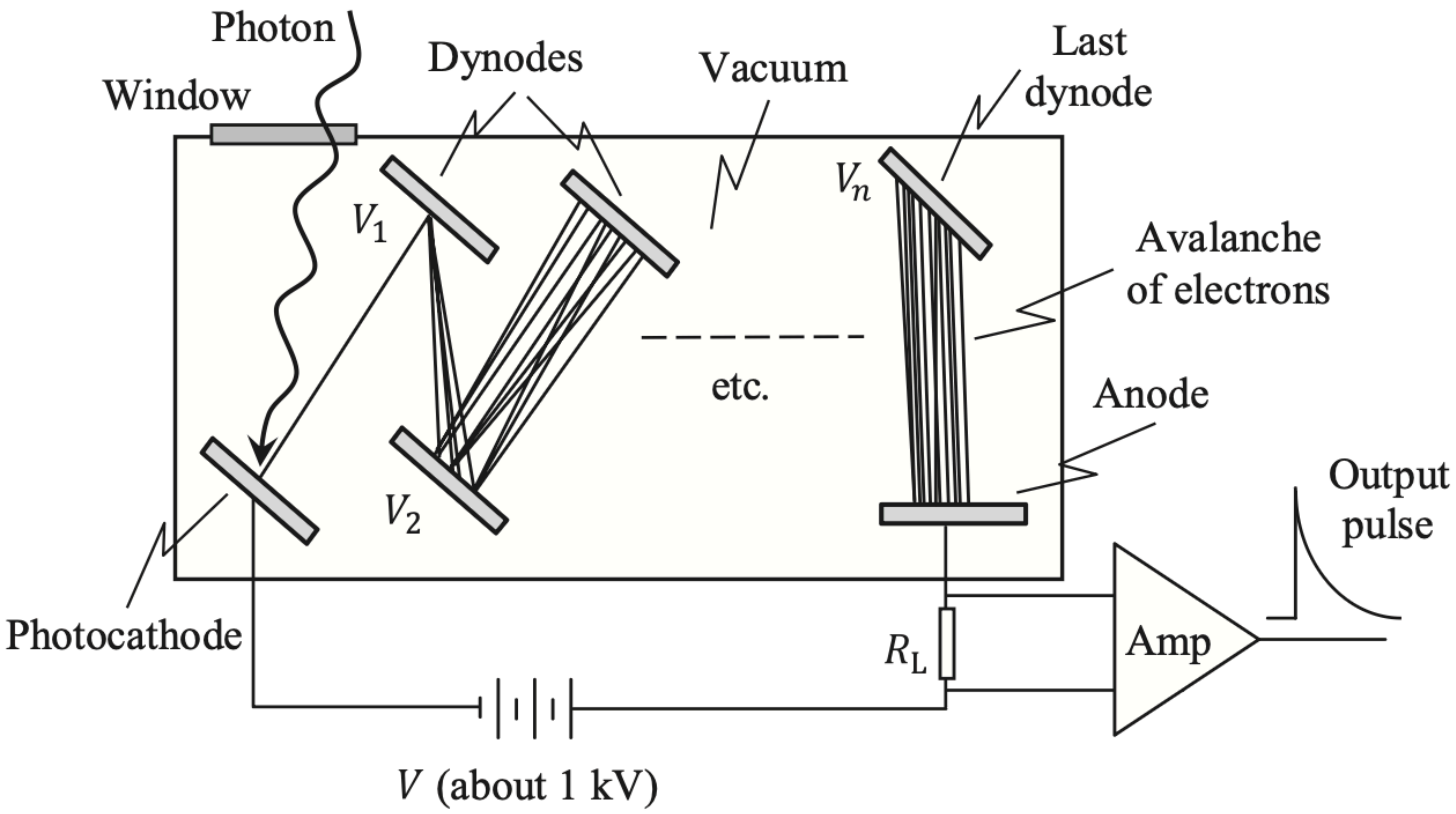

converts a low-intensity light signal to a current signal

Single photon at the input causes an avalanche of 10^5 electrons

PhotoMultiplier Tube (PMT)

Dark Current

- Thermally excited emission of electrons from the photo-cathode
- Ionising events from unknown sources

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Dark Current

Thermally excited emission of electrons from the photo-cathode

Ionising events from unknown sources

(i) Find V_{opt} : below V_{opt} the signal is too low, above V_{opt} the dark current becomes high;

(ii) Tube is cooled (typically to −20 C) reducing the thermal emission exponentially

(iii) The output pulses are examined by pulse height discrimination to reject contamination