Detection

PHY451

September 17, 2014

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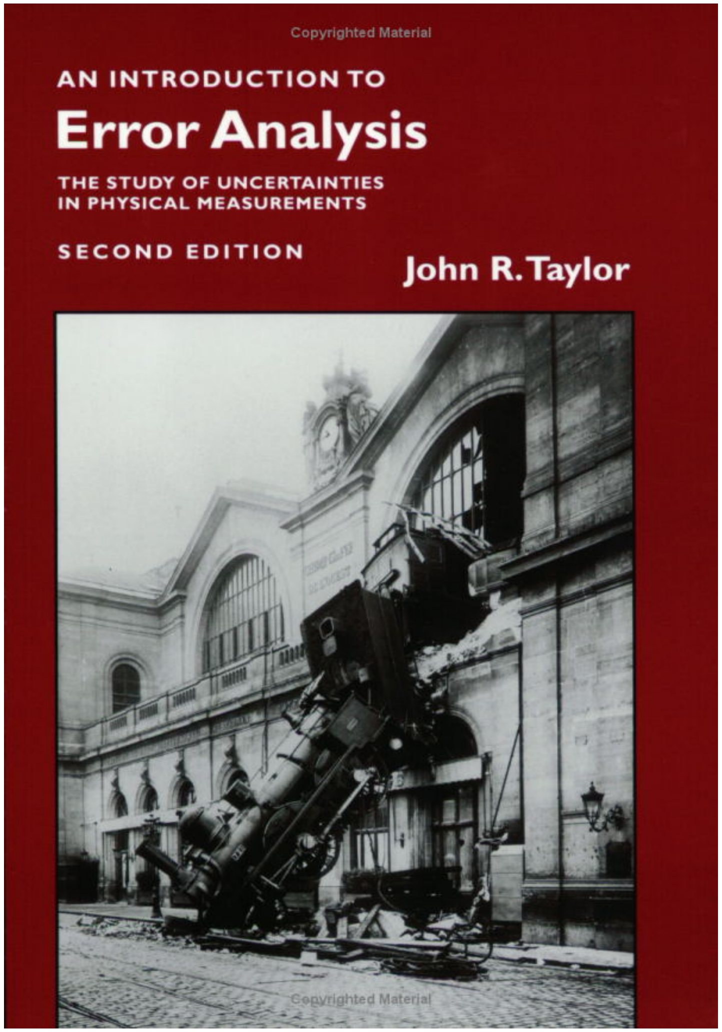
References

- **"An Introduction to Error Analysis, The Study of Uncertainties in physical measurements", 2nd edition, John. R. Taylor, 1997.**
- **http://www.lon-capa.org/~mmp/labs/error**
- **Class Website**
  - **http://www.pa.msu.edu/courses/PHY451/**
  - **Some materials pass word protected due to copyright issues**
  - **Pass word** wuli451!



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Types of Detectors

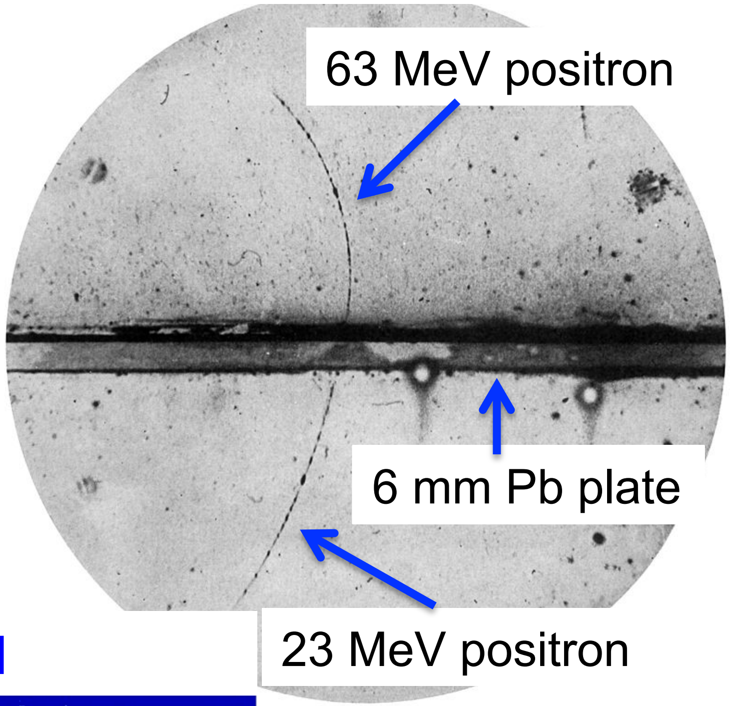
- Vapor / liquid detectors – ionizing radiation
  - “Cloud Chamber”
  - “Bubble Chamber”
- “Wire” detector – ionizing radiation
  - Single wire chamber – non-linear region - Geiger Mueller Tube
  - Single/multi wire chambers – in proportional region – wire chamber(s)
- Scintillator detector – ionizing radiation
- Semiconductor detector – ionizing radiation
  - Silicon
  - Germanium
- Other – visible light
  - Silicon photodiode
  - Photomultiplier tube (PMT)
- Other – temperature
  - Thermocouple
  - Pressure
  - Resistance

Vapor / Liquid Detectors

Wilson cloud chamber

- Supersaturated vapor, droplets form around charged particles left by passage of e.g. protons – showing path in magnetic field ➔

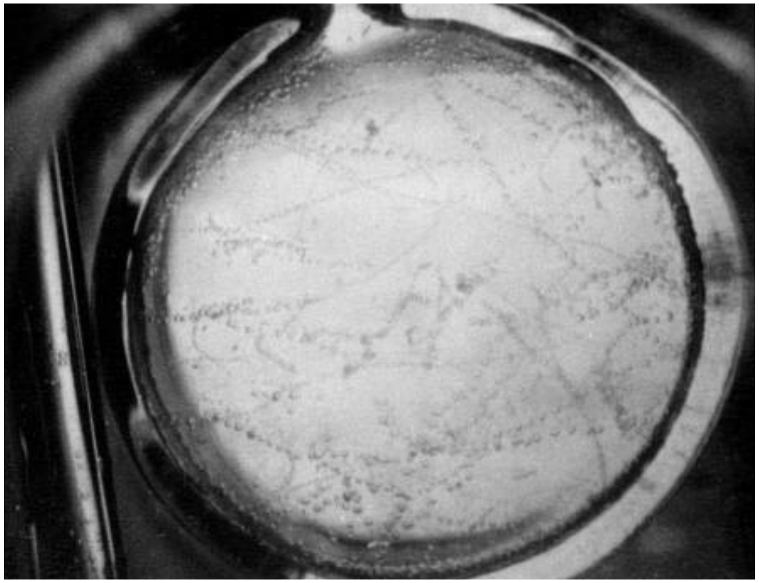
First positron ever observed.



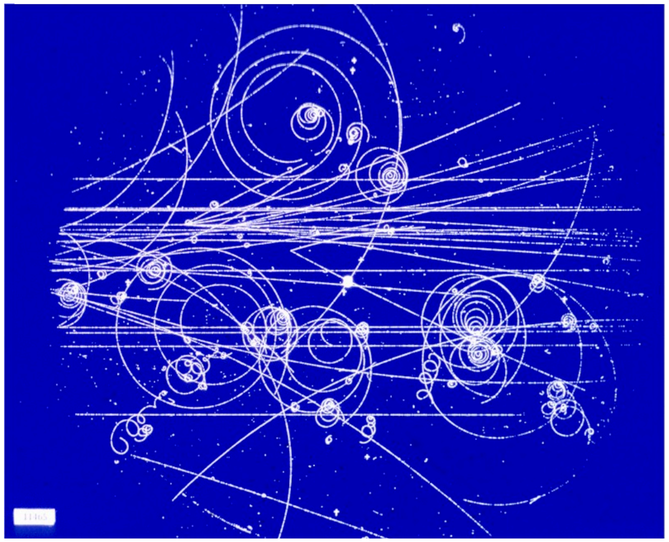
Bubble chamber

- Superheated liquid - droplets form around charged particles left by passage of e.g. protons – showing path in magnetic field

Tracks in a hydrogen bubble chamber 1954



CERN



Single Wire Chamber - 1

Chamber filled with low pressure (0.1 atm) inert (noble) gas

- **Detects gamma or x-ray or electrons or particles (e.g. He)**

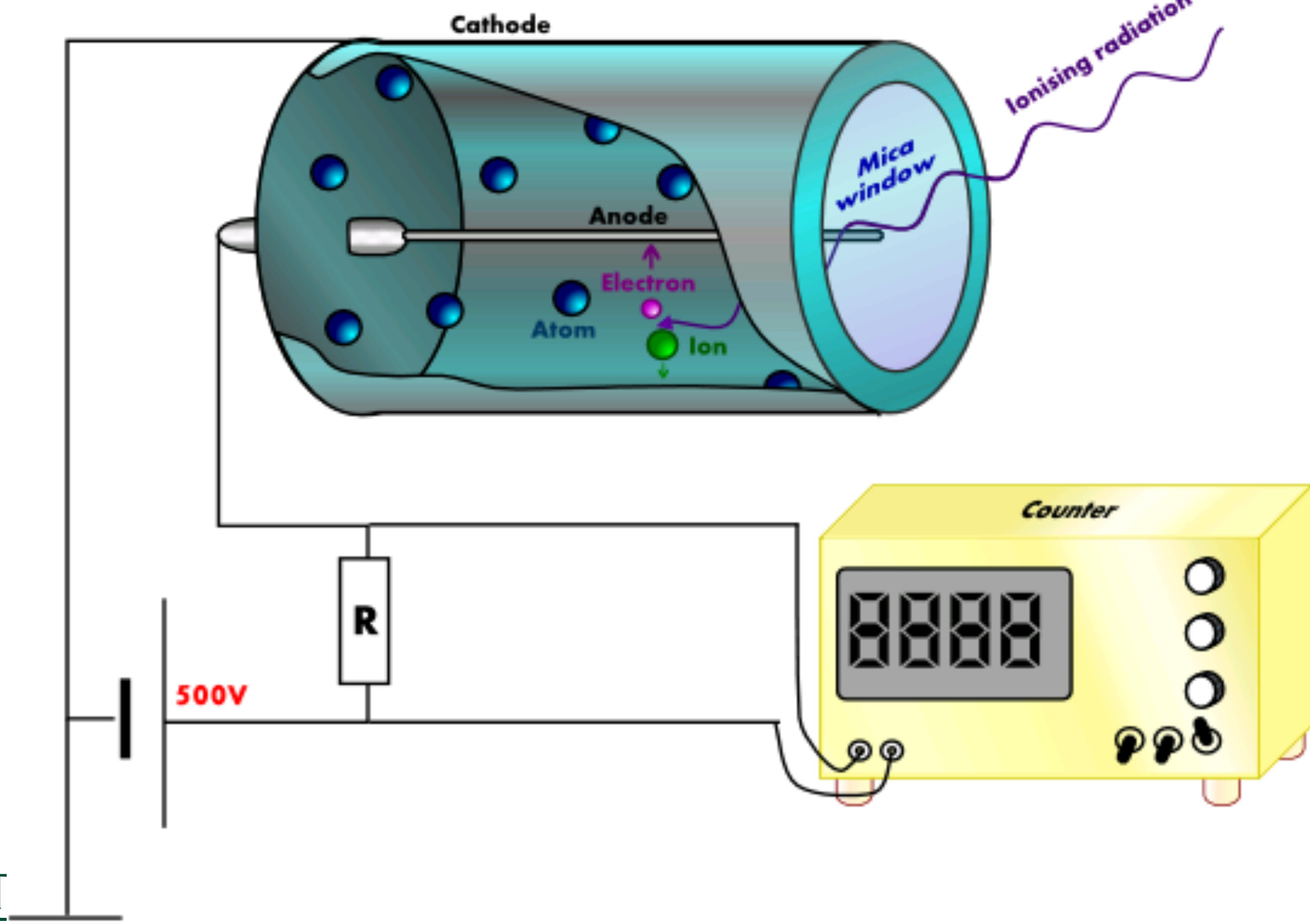


Figure from http://en.wikipedia.org/wiki/Geiger–Müller_tube

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Single Wire Chamber - 2

Response depends on voltage

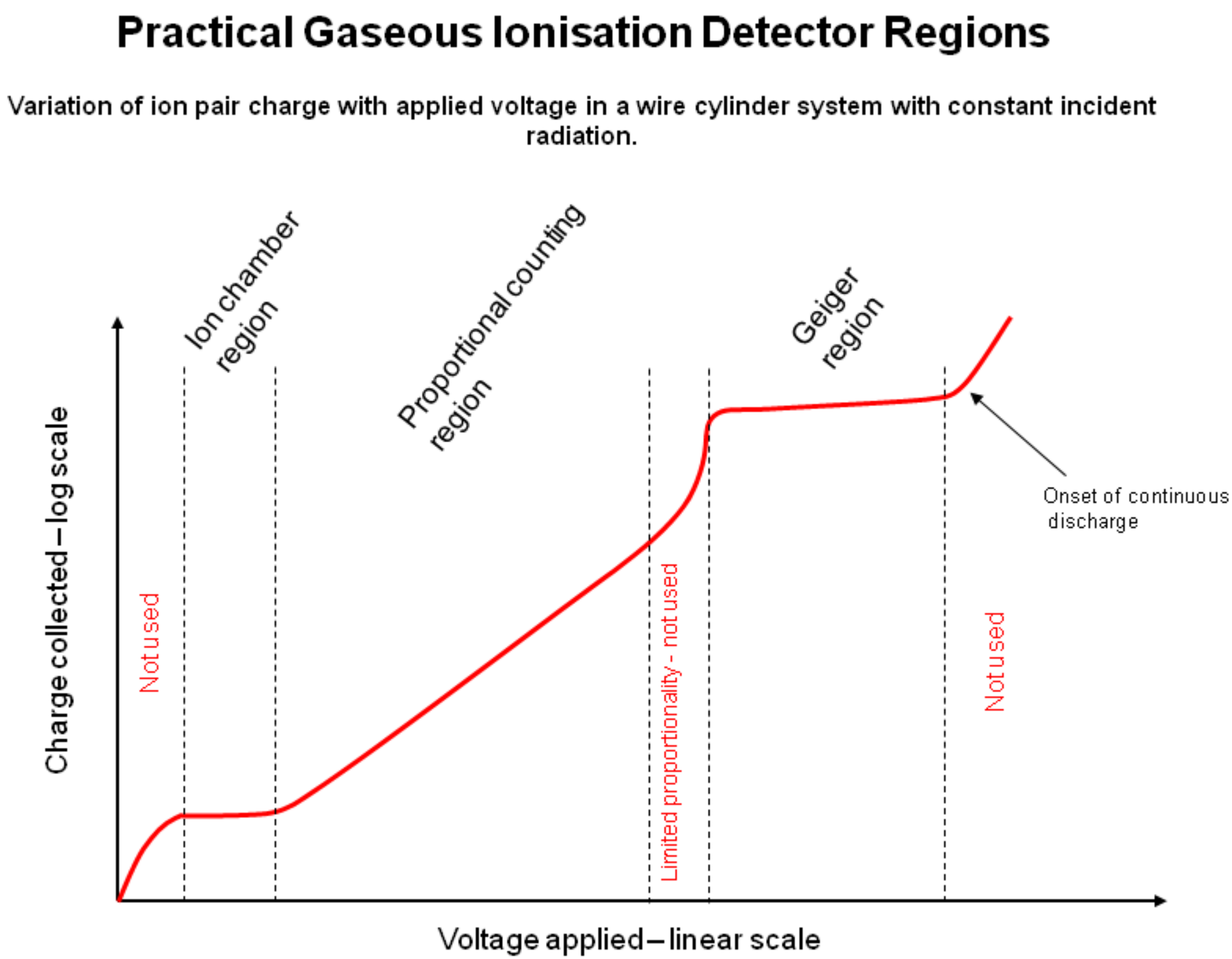

Figure from http://en.wikipedia.org/wiki/Geiger–Müller_tube

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Single Wire Chamber - 3

Response depends on counting rate –

Van Allen radiation belt “discovered” by dead time – no response (since not enough recovery time) - during very intense radiation (radiation belts)

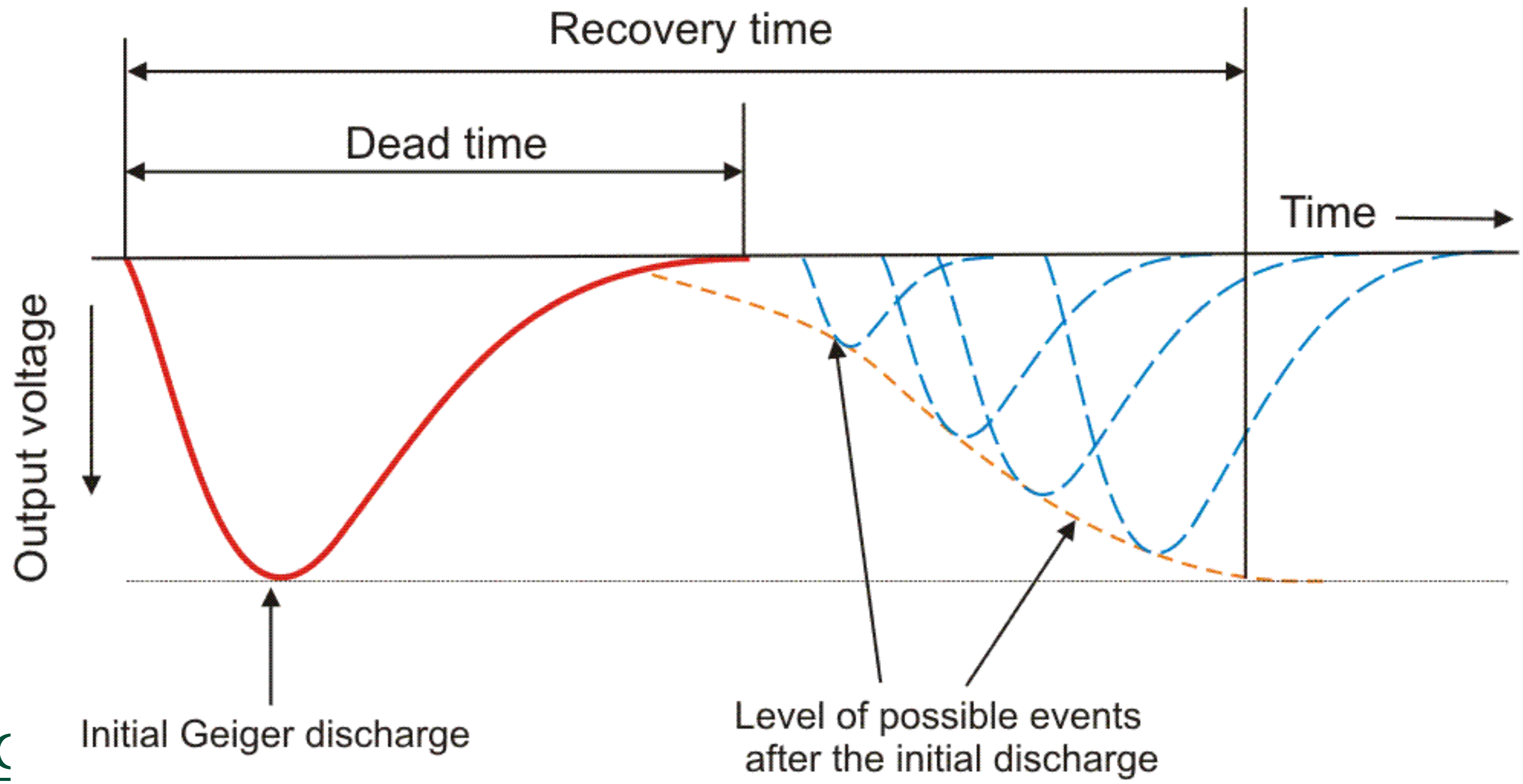

Figure from http://en.wikipedia.org/wiki/Geiger–Müller_tube

Multi-wire Chamber

Multiple "single wire chambers" ➔if voltage run in proportional zone – output proportional to particle energy or can be run in ion chamber region giving position

Get position information especially if have a 2^{nd} chamber rotated by 90^{o} to 1^{st} ➔ get "x" from 1^{st} chamber & then "y" from 2^{nd} chamber – defining point

multiple separated chamber pairs ➔ define trajectory

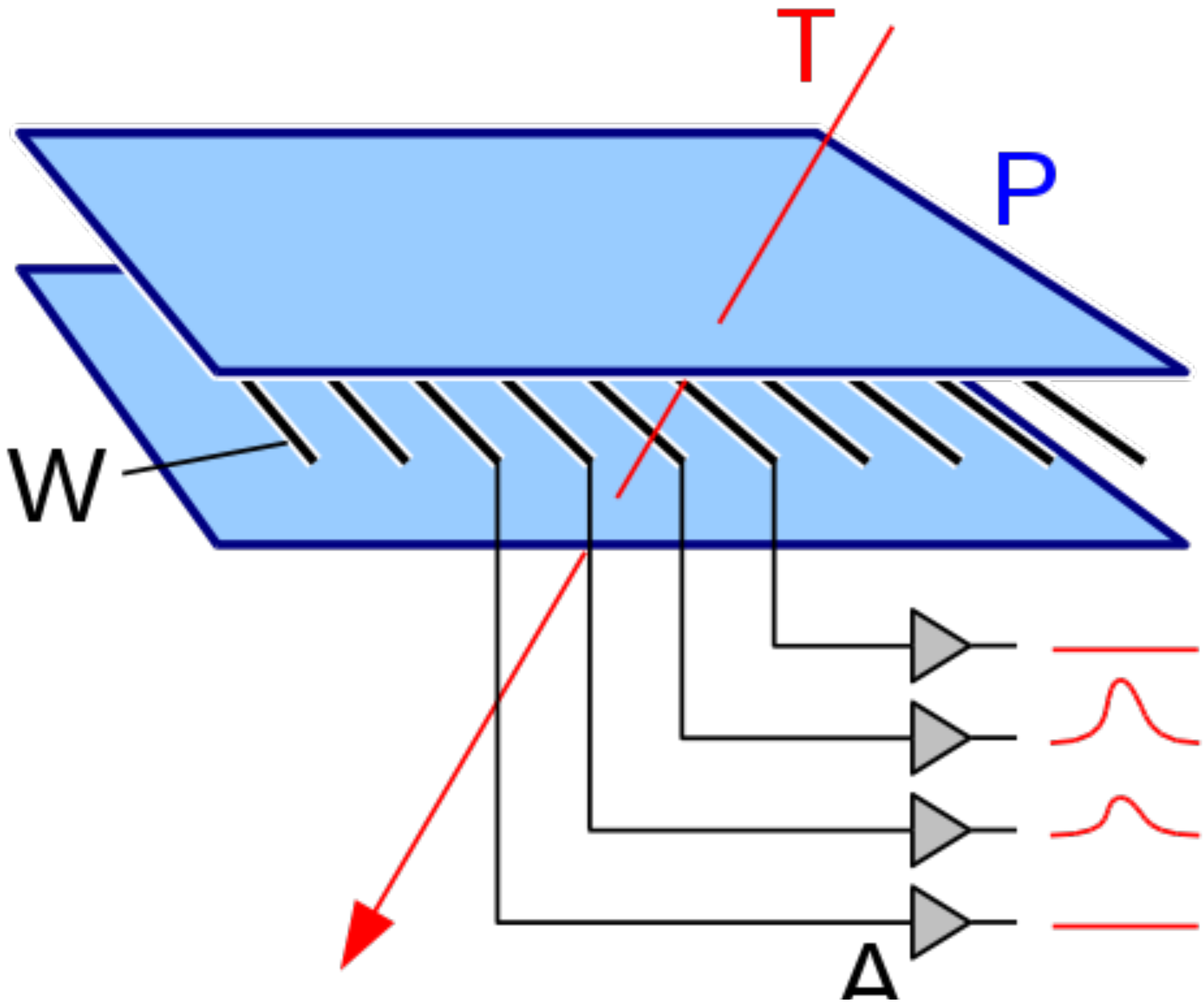

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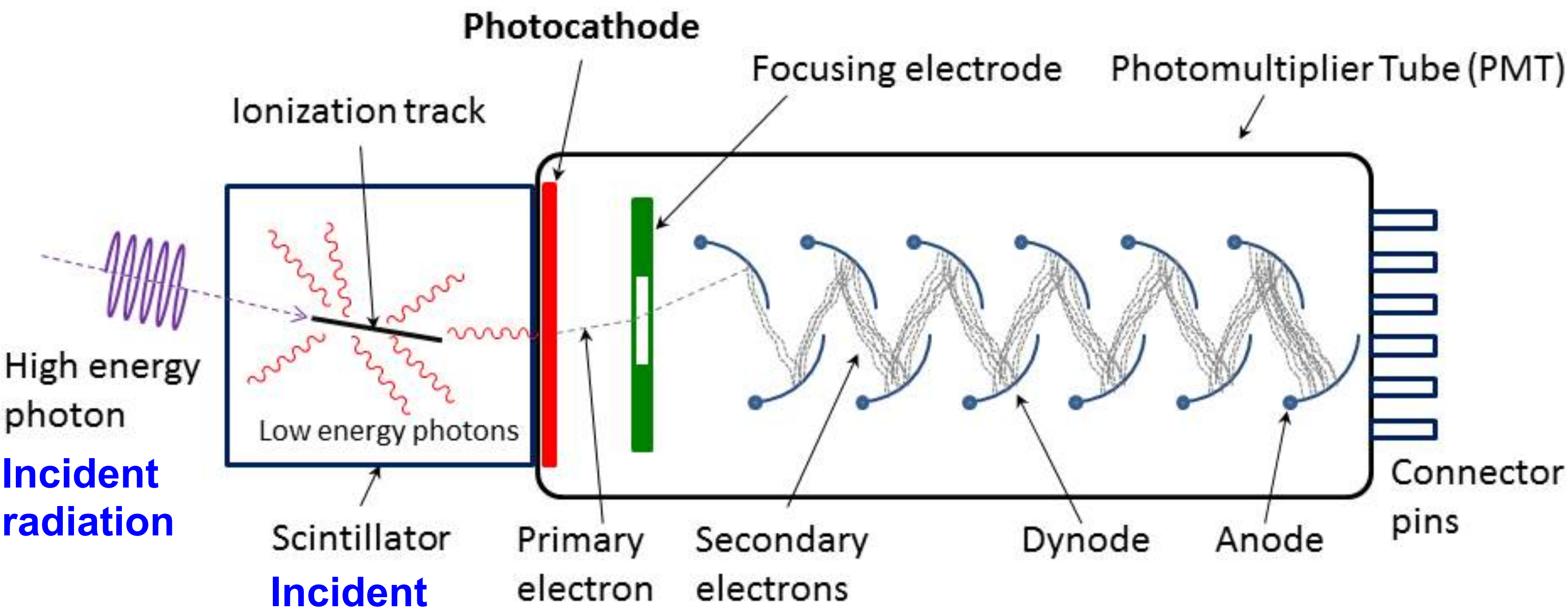
Figure from http://en.wikipedia.org/wiki/Wire_chamber

Scintillator - 1



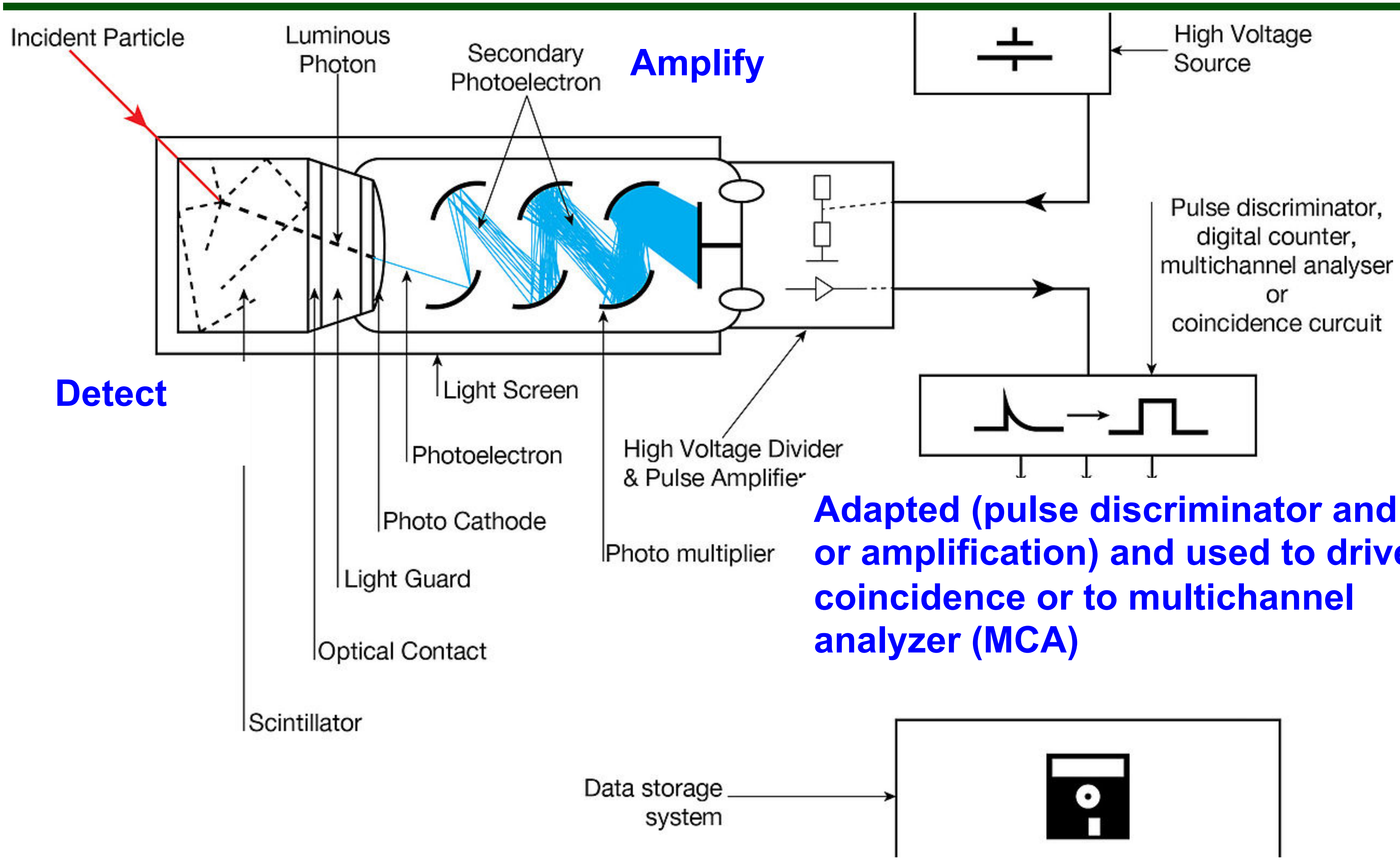
Incident radiation

Incident radiation causes light (photons) in scintillator - e.g. sodium iodide

Light converted to amplified (each dynode accelerating and increasing number of electrons) voltage pulse by Photomultiplier Tube – PMT

Figure from http://en.wikipedia.org/wiki/Photomultiplier

Scintillator - 2



Adapted (pulse discriminator and / or amplification) and used to drive coincidence or to multichannel analyzer (MCA)

Figure from http://en.wikipedia.org/wiki/Photomultiplier

Semiconductor - Silicon

Figure from ww.canberra.com

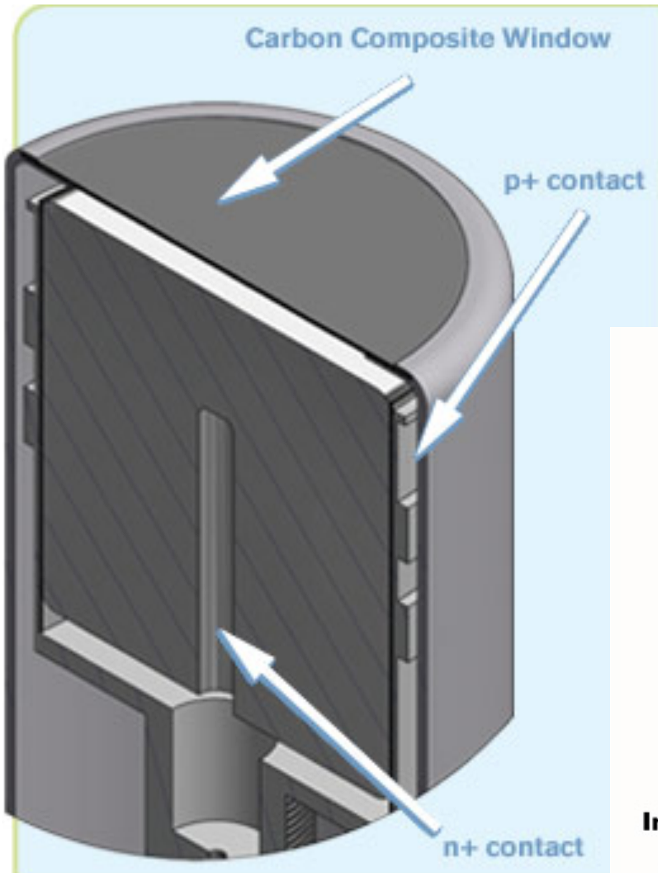
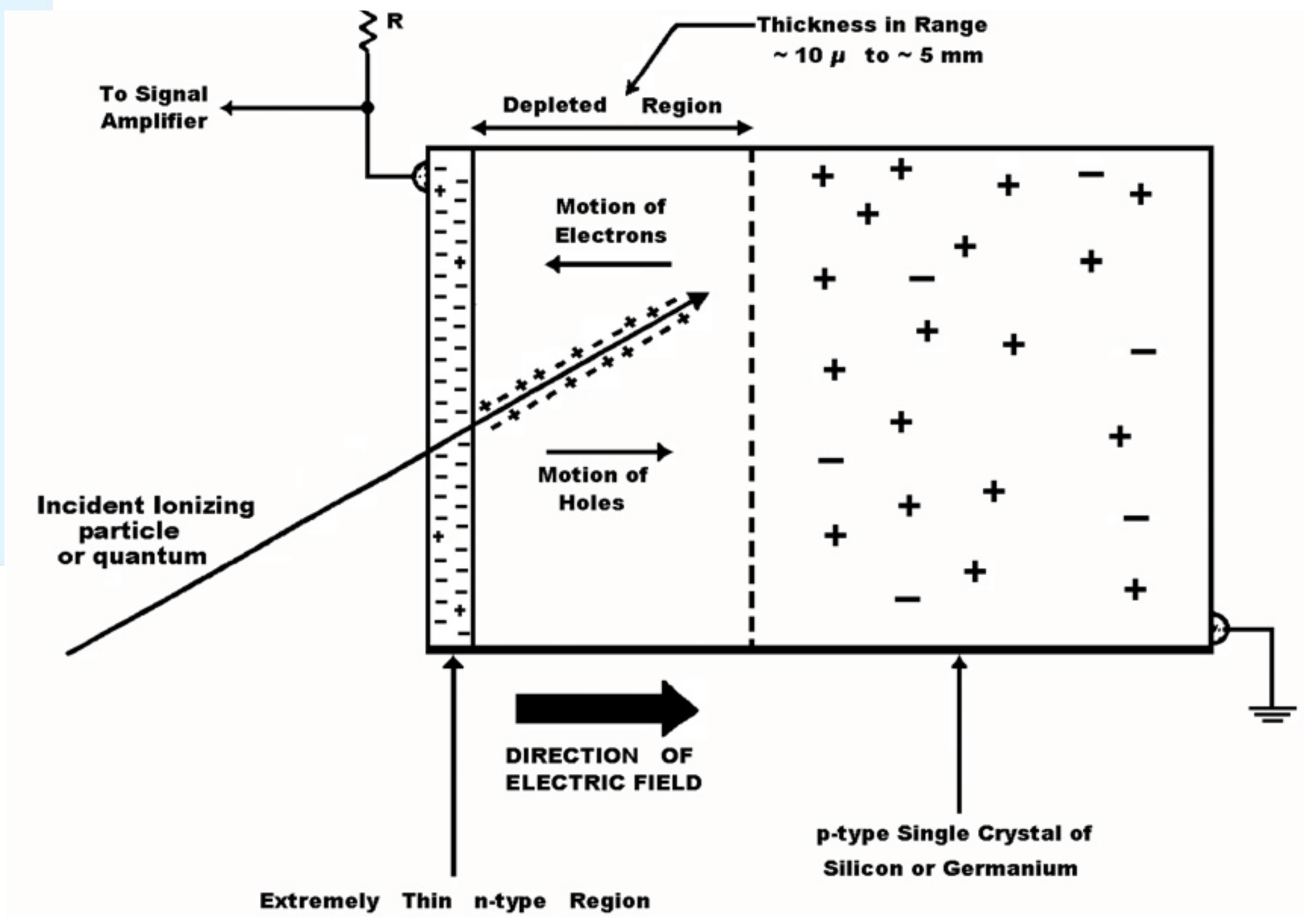


Figure from http://nsspi.tamu.edu/nsep/courses/basic-radiation-detection/semiconductor-detectors/introduction/introduction



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Semiconductor - Germanium

Ge detector ➔ cold (liquid Nitrogen = 77K) makes operational and reduces background ➔ very good resolution

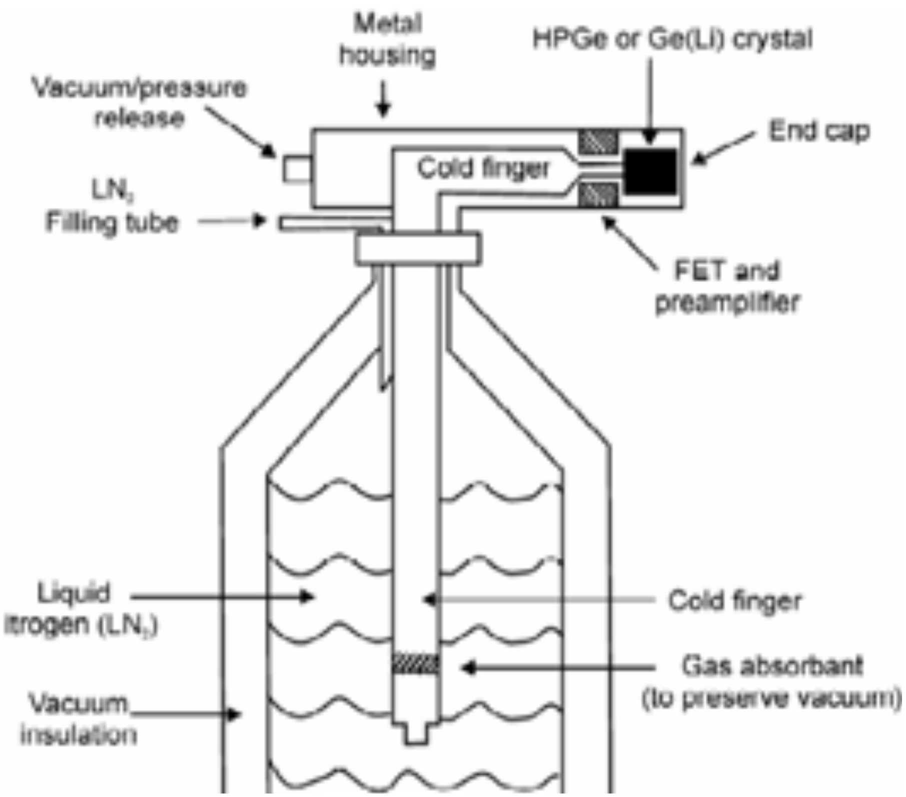
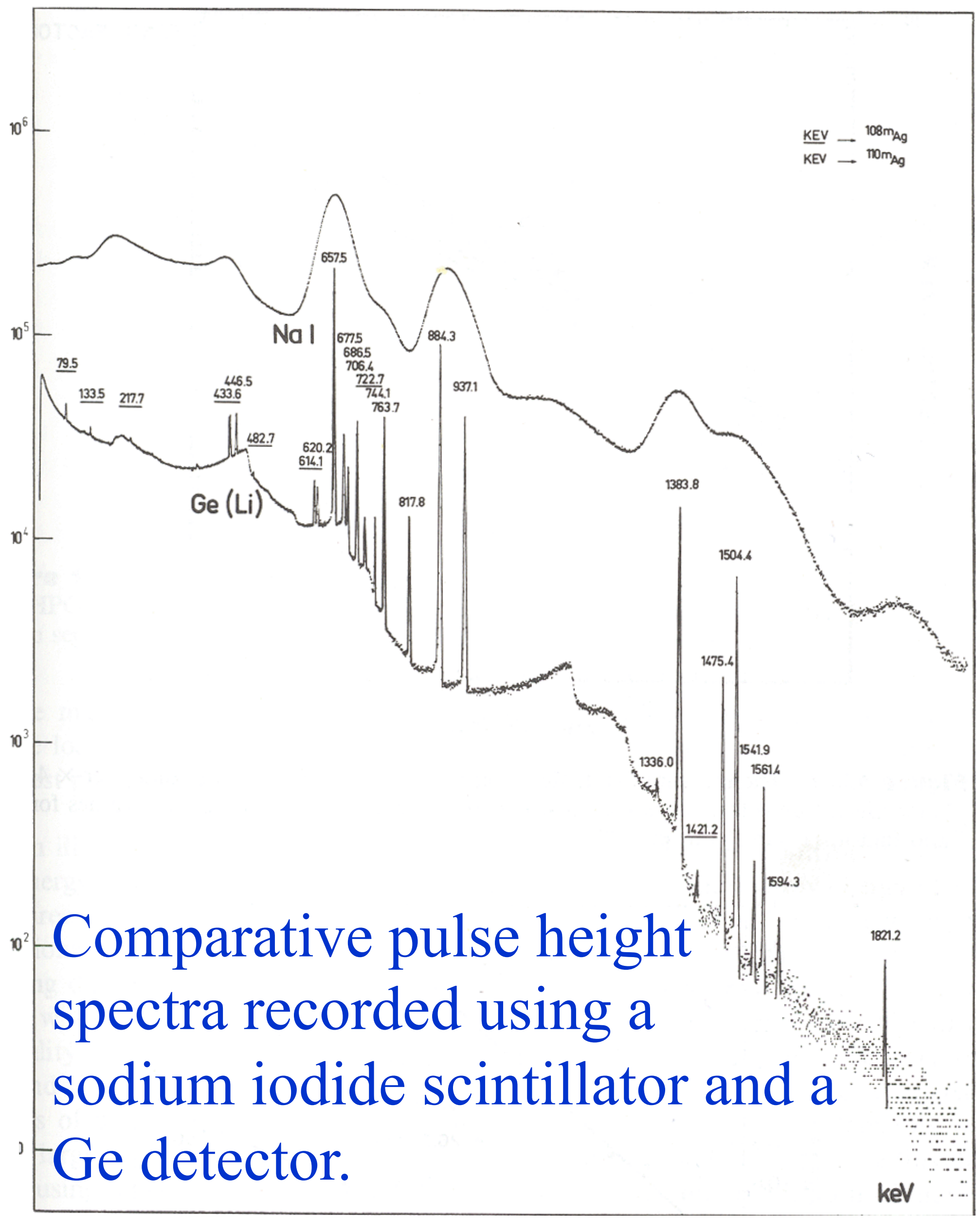


Figure from http://www.expertsmind.com/topic/semiconductor-detector/resolution-of-a-detector-912061.aspx



Comparative pulse height spectra recorded using a sodium iodide scintillator and a Ge detector.

Post-detector Electronics - 1

Discriminator → **Amplifier** → **Multichannel Analyzer** → **PC**

- **Detector – detects presence of radiation (γ-ray, x-ray, electron etc.)**
  - “detection” causes output pulse (voltage as function of time)
- **Post-detector Electronics**
  - Pulse (voltage as function of time) shaping
    - » Removes “noise” (lower voltage) with Discriminator
    - » Increase voltage appropriate for follow-on electronics with Amplifier
      - If voltage is proportional to e.g. energy of particle, amplify to get pulse into range useful for equipment

Post-detector Electronics - 2

Discriminator → **Amplifier** → **Multichannel Analyzer** → **PC**

- Post-detector Electronics - cont'd
  - MultiChannel Analyzer (MCA)– 2 steps
    - » Analogue (Pulse height, voltage) to Digital (number) Conversion (ADC)
      - Typically base 2 (2^n) # resolution – e.g. 64, 128, 256, 512, 1024, 2048, 4096 resolution of digital representation of pulse
      - E.g. if MCA full scale (max.) voltage is 10 volts & 4096 full scale → then voltage resolution ~10/4096~2.44mV
    - » Digital numbers – Analyzed (binned) into multiple channels to produce Pulse Height Spectrum
      - e.g. last (4096 bin) would have voltages ≥10,000-2.44mV

Post-detector Electronics - 3

Discriminator → **Amplifier** → **Multichannel Analyzer** → **PC**

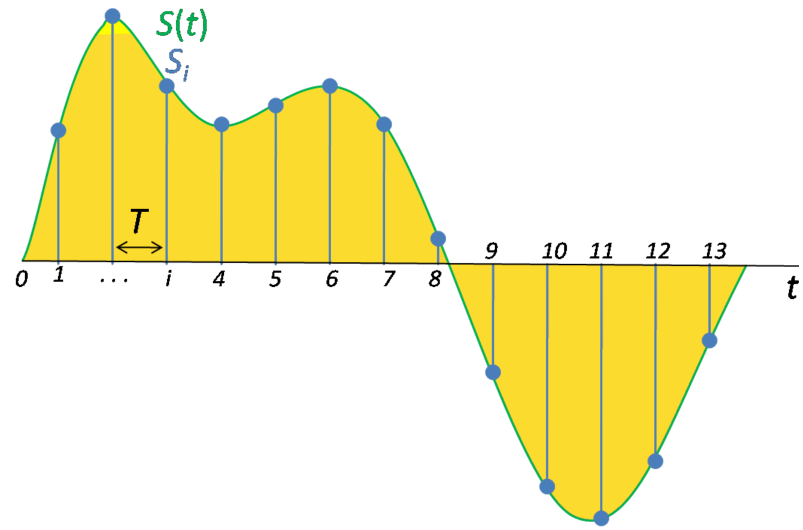
E.G. – Detector detects gamma rays with peak values of 0.5, 1, and 2 keV

- **Shape pulse so little or no noise (not many counts in lowest channels of MCA) & highest energy signals (2 keV) about 8 volts (assuming 10 V full scale for MCA)→8 volts/2 keV = 4 volts/keV**
- **Then peaks at voltages roughly 4 volts/keV x (0.5, 1, 2 keV) = (2, 4, 8 volts)**
- **If MCA has 4096 channels for 10 volts or 409.6 channels/volt**
- **Then peaks at roughly 409.6 channels/volt x (2, 4, 8 volts) = (channel # 819,1638,2277)**
- **Can calibrate (using known sources) energy (e.g. keV) per channel. Can then identify energy of unknown particles, relative number of particles as function of energy & attributes – which may be source or detector related like e.g., width of energy peak, relative strength of peaks (representing some process) etc.**

Post-detector Electronics - 4

Element of MCA can be sample rate of ADC

- **For some applications only want pulse peak value since correlated with energy**
- **So sampling rate has mostly to do with accurately determining peak**
- **But generally pulse shape is continuous & want good representation**

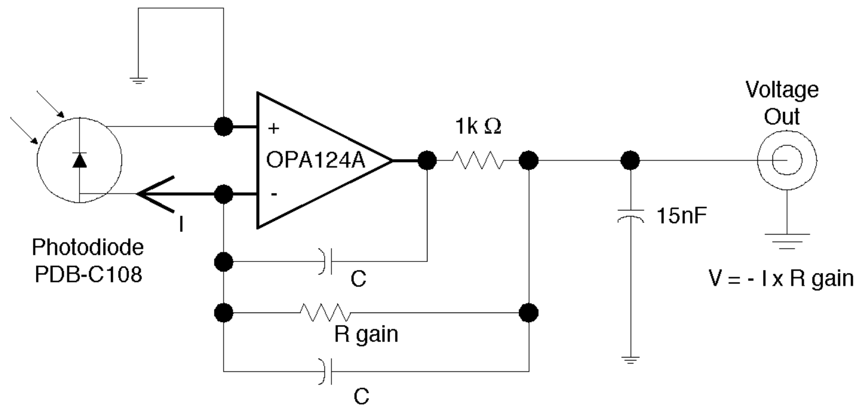


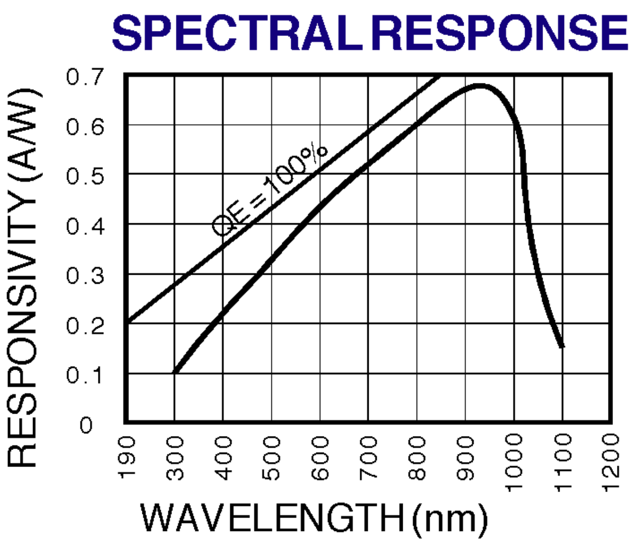
- **Discrete digital values to represent pulse**
- **Sampling rate (sample every T time) determines number of values (13 in example figure) – more values better representation – but more ADC activity and more data**
- **For faster varying signal want faster sample rate**
  - **Music ➔ human ear <20 kHz frequencies ➔can capture "human ear quality" by sampling rate of ~40 kHz**
    - **Music record ➔ADC produces digitized version of wave form written to e.g. CD**
    - **Music play ➔ Digital Analogue Conversion (DAC) produces voltage version of wave form input to headphone/speaker**
  - **If detector pulse length is e.g. 1 μs ➔ and want 10 points describing pulse shape then need to sample every 0.1 μs or at rate of 10 MHz**

See http://en.wikipedia.org/wiki/Sampling_(signal_processing)

Silicon Photodiode – optical pumping

Figure from http://www.pa.msu.edu/courses/PHY451/Experiments/optical_pumping/manual_teachspin_optical_pumping.pdf





A light (photon) detector is a silicon photodiode

The spectral response at 795 nm is about 0.6 A/W (for PDB-C108)

- more photons ➔ more signal
- but wavelength dependence (may not affect result)

Photomultiplier Tube - Sonoluminesence

Eye can see visible light from sonoluminesence
- but use Hamatsu R955 Photomultiplier Tube to determine duration and phase w.r.t. mechanical drive
- Rise time ~2.2ns

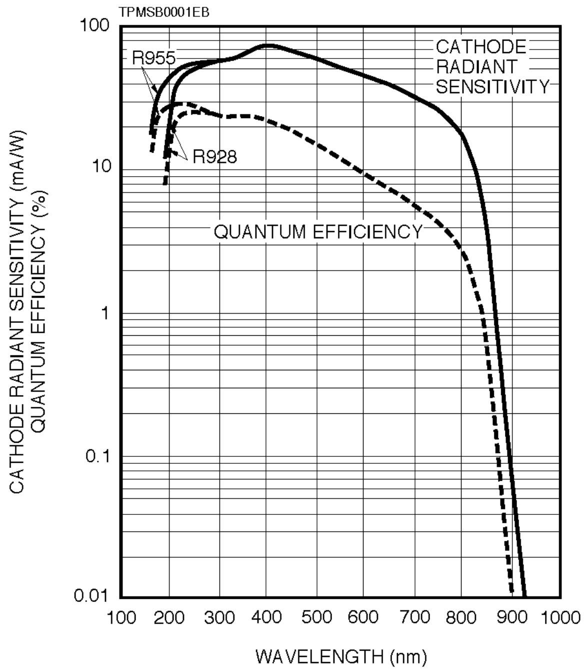


Figure 2: Anode Luminous Sensitivity and Gain Characteristics

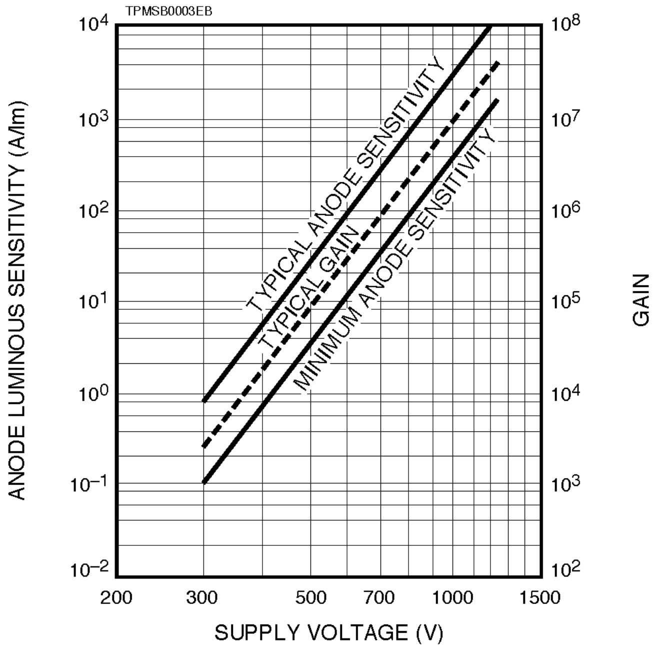
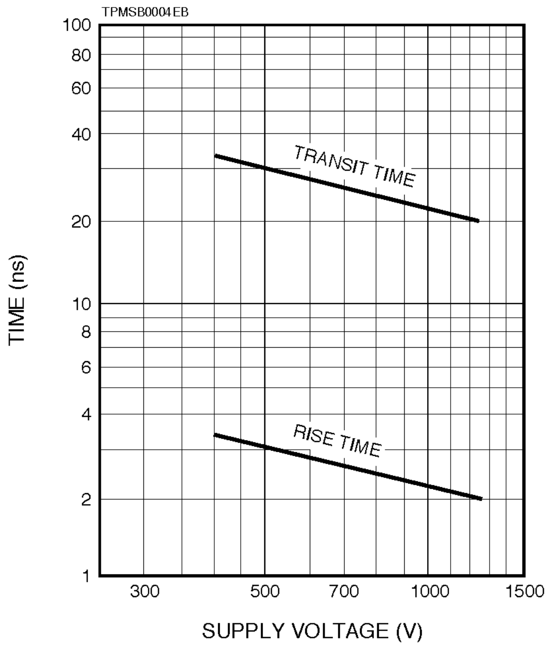


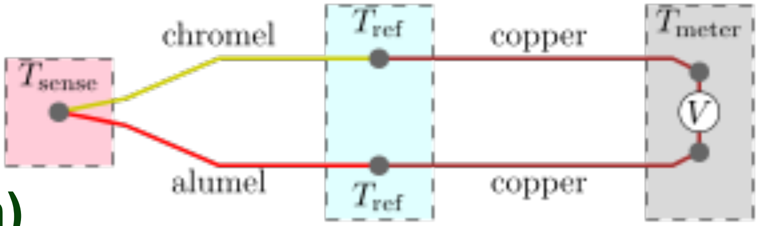
Figure 3: Typical Time Response



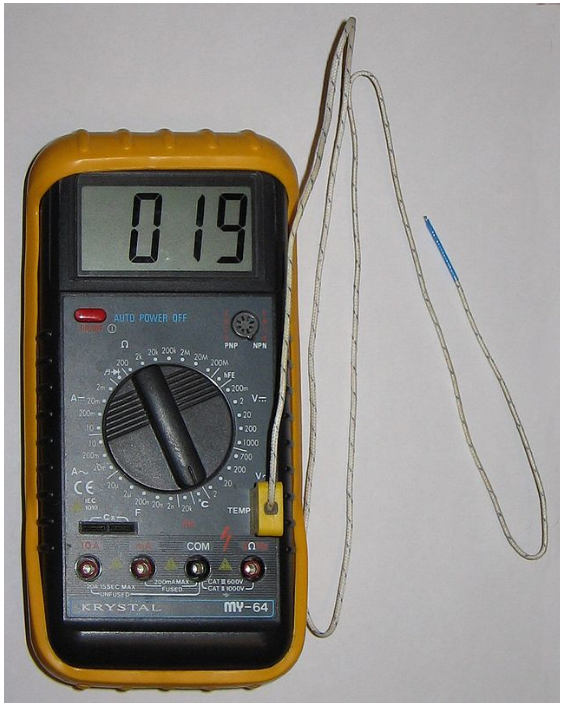
Temperature - 1

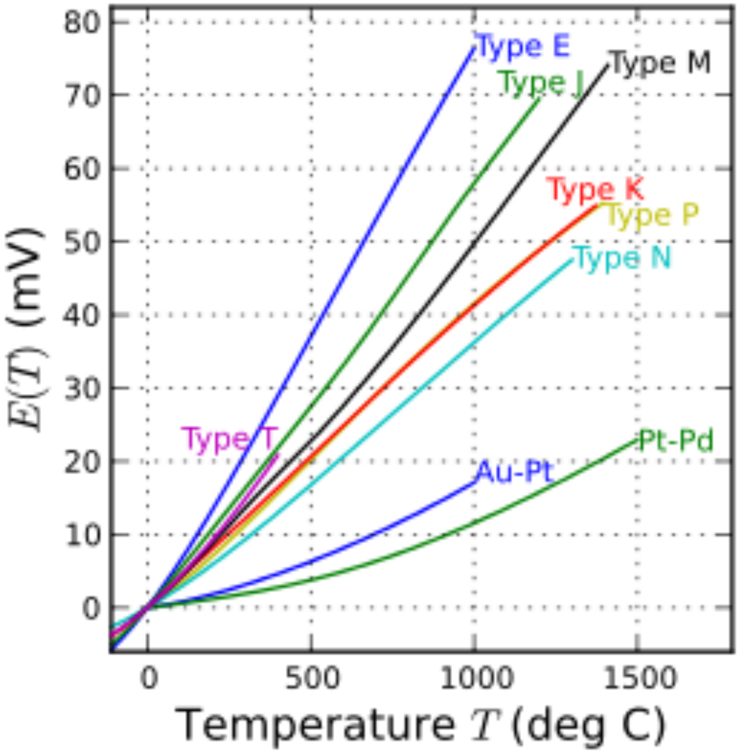
Thermocouple - see - http://en.wikipedia.org/wiki/Thermocouple

- **Conductor subjected to thermal gradient produces voltage. Use 2 dissimilar conductors so can connect "hot"/"cold" sensor to meter without distorting reading.**



- **Response depends on Type (combination)**
- **Type depends on application**
- **E- (chromel/constantan) J (iron-constantan)**
- **K (chromel- alumel) – most common, M (Ni/Mo-Ni/Co), N (Nicrosil-Nisil)**
- **Au-Pt, Pt-Pd**





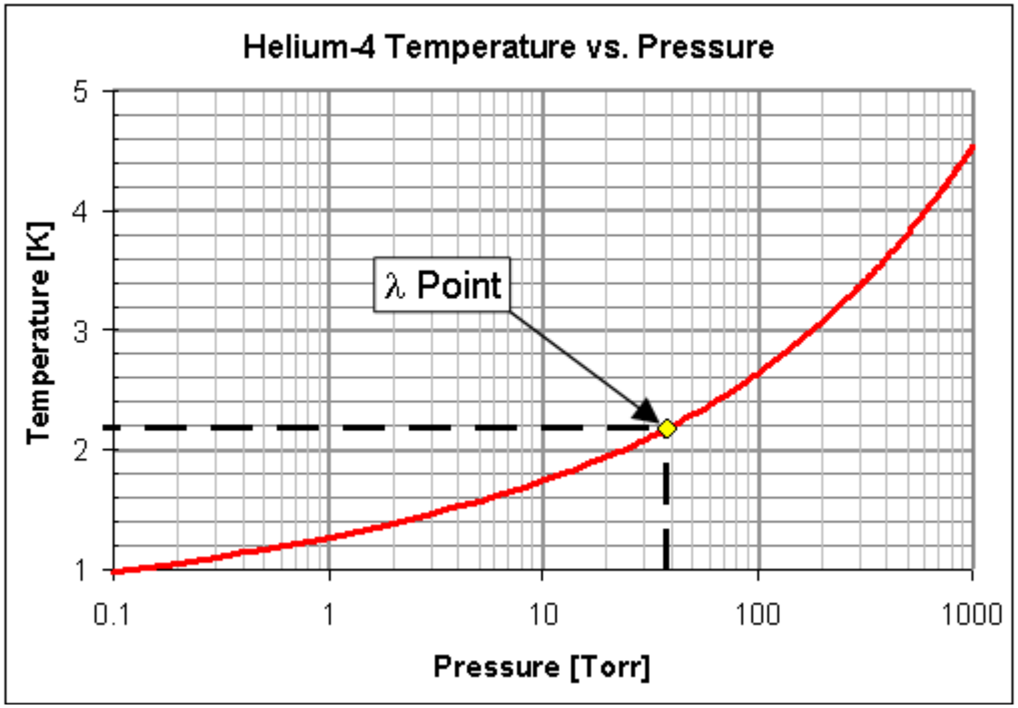
Temperature - 2

Ideal Gas Law

- Temperature = T = PV/nR
  - P=pressure, V = volume, nR α # molecules in V
  - If V/nR constant then, T α P ➔ determine T by measuring P

Corrections to Ideal gas law (more quadratic dependence) – especially at lower temperatures

- Helium 4 – from http://en.wikipedia.org/wiki/Superconducting_radio_frequency
- λ point ~2.2 K temp. liquid He transitions to superfluid
- Nb-based superconductors used in magnets and accelerating cavities require temperatures <~4K (low temperature)
- Refrigerators based on Helium 4 as cryogen necessary to obtain and maintain operating temperature
- Operation at <2K desirable so as to not affect high Q ($>10^9$) accelerating cavities

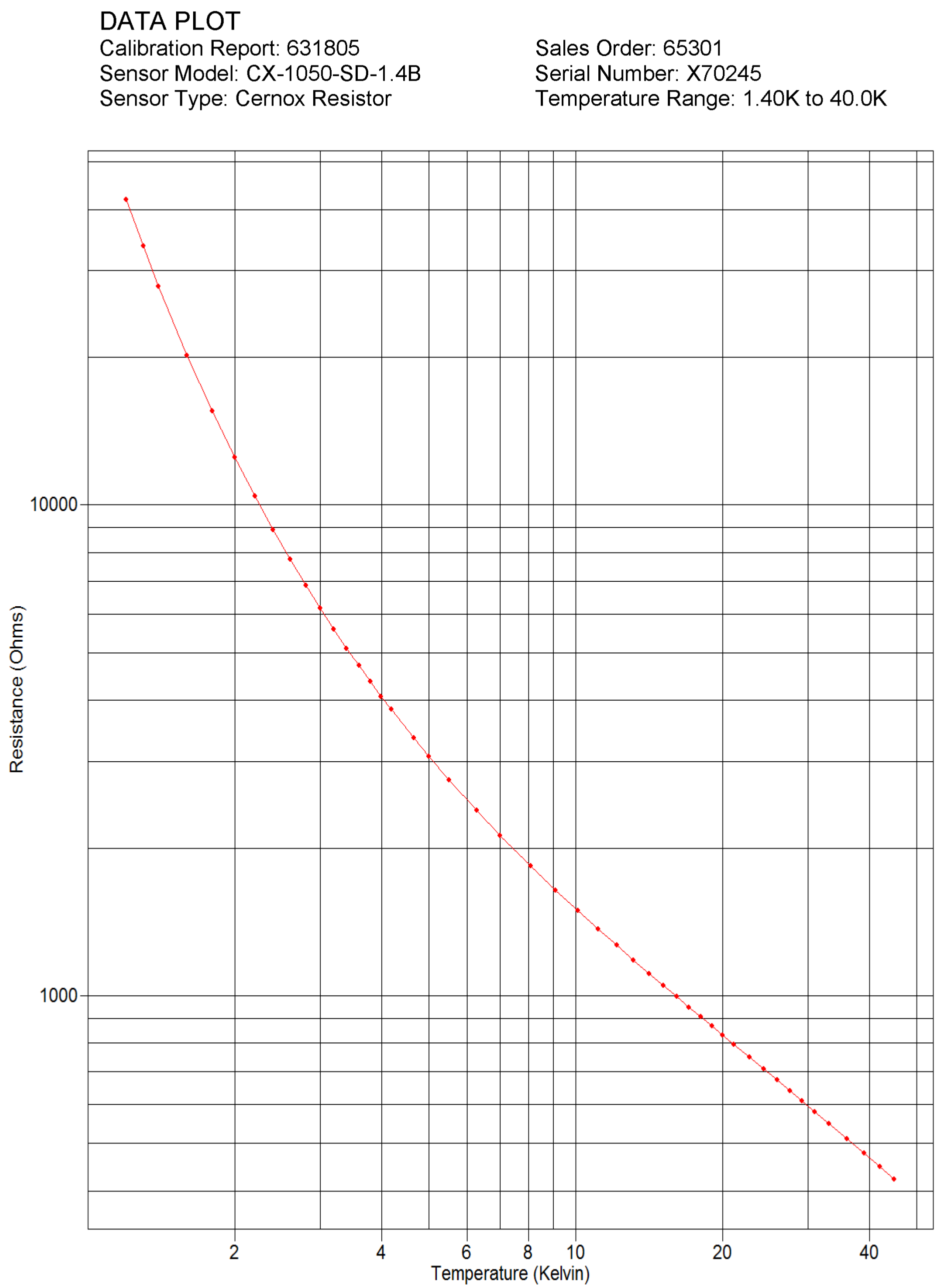


Temperature - 3

Resistor's resistance changes as a function of temperature

By measuring (and calibrating) resistance as function of temperature and fitting to empirical function for interpolation ➔ can be used as thermometer

Used on for He experminent



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