Proportional Counters

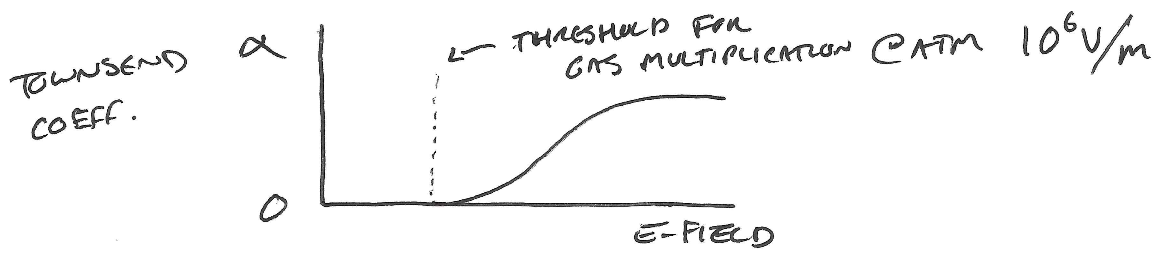
- OPERATE IN PULSE MODE

- RELY ON PHENOMINA OF GAS MULTIPLICATION. WHICH AMPLIFIES CHARGE REPRESENTED BY ORIGINAL ION PAIRS CREATED.

- PULSES ARE CONSIDERABLE LARGER THAN THOSE FROM ION CHAMBER

- APPLICATION IS DETECTION & SPECTROSCOPY OF LOW ENERGY X-RAY RADIATION.

- GAS MULTIPLICATION: INCREASE ELECTRIC FIELD WITHIN THE GAS. DETECTOR
  - AT LOW FIELD ELECTRONS/ION DRIFT. IONS COLLIDE. ~~BOTH~~ BECAUSE OF LOW MOBILITY POSITIVE & NEG. IONS ACHIEVE LOW VELOCITY
  - ELECTRONS ARE EASILY ACCELERATED AND HAVE SIGNIFICANT K.E. BEFORE A COLLISION, IF GREATER THAN IONIZATION ENERGY OF A NEUTRAL GAS MOLECULE, AN ADDITIONAL ION PAIR IS CREATED



LIBERATED ELECTRON CAN LEAD TO CREATION OF FURTHER IONIZATION, AND SO IT GOES..

THIS PROCESS: TOWNSEND AVALANCHE.

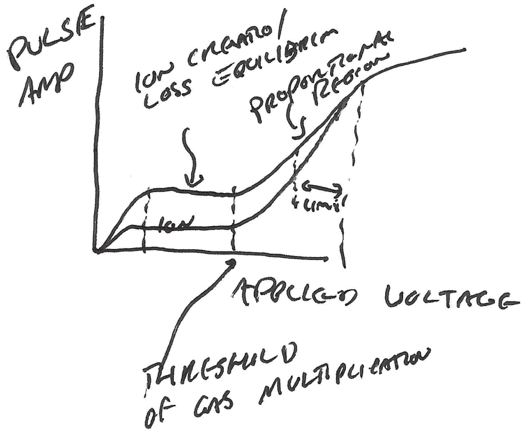
- FRACTIONAL INCREASE IN NUMBER OF ELECTRONS PER UNIT PATH LENGTH IS GOVERNED BY

$$\frac{dn}{n} = \alpha \, dx$$

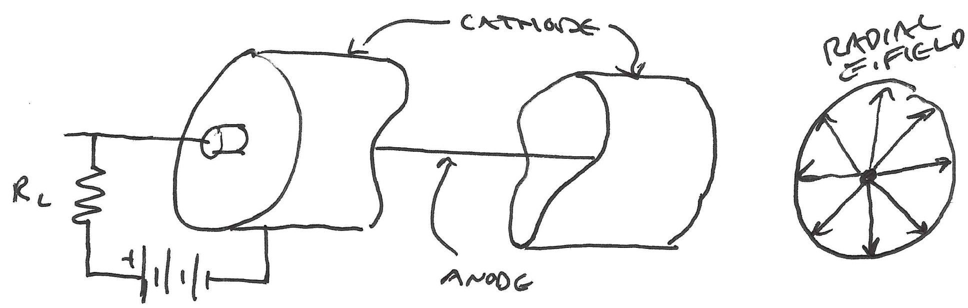
(α ← TOWNSEND COEFF, ZERO BELOW THRESHOLD)

DENSITY OF ELECTRONS GROWS EXPONENTIALLY

$$n(x) = n(0) \, e^{\alpha x}$$



SPACE CHARGE CREATES A LIMITED PROPORTIONALITY



DETECTOR GEOMETRY

- HIGH ELECTRIC FIELD IS REQUIRED, CYLINDRICAL GEOMETRY IS DESIRABLE TO ENHANCE E-FIELD
- ELECTRONS MUST BE ATTRACTED TO ANODE

- GAS MULTIPLICATION REQUIRES LARGE ELECTRIC FIELD

$$E(r) = \frac{V}{r \ln(b/a)}$$

V = VOLTAGE BETWEEN ANODE + ELECTRIC FIELD

a = ANODE WIRE RADIUS

b = CATHODE INNER RADIUS

EXAMPLE: V = 2000 V APPLIED

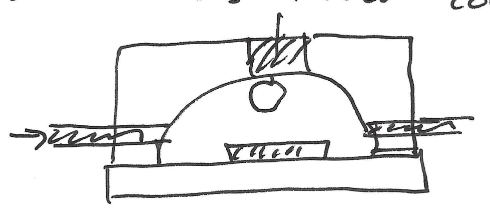
a = 0.008 cm, b = 1.0 cm E-FIELD AT SURFACE IS 5.18×10^{6} V/m

*COMPARE TO PARALLEL PLATE DETECTOR WITH SPACING OF 1CM V REQUIRED WOULD BE 51,800 V FOR SAME FIELD

PROBLEMS + SOL'NS

- E-FIELD VERY SENSITIVE TO VARIATIONS IN ANODE WIRE DIAMETER: MANUFACTURING CONTROL
- END EFFECTS, FIELD TUBES OF LARGER DIAMETER TO DROP BELOW THRESHOLD FIELD.

- ATTENUATION OF SIGNAL BY WINDOW: SOL'N WINDOWLESS FLOW COUNTER



FILL GASES + GAS MULTIPLICATION FACTOR

GAS MULTIPLICATION IS CRITICALLY DEPENDANT ON MIGRATION OF FREE ELECTRONS, MUST USE GASES W/ LOW ELECTRON ATTACHMENT COEFF. AIR IS NOT ONE!

MUST BE FREE OF OXYGEN + OTHER ELECTRONEGATIVE GASSES.

~~EXAMPLES~~ SUCH AS Ar-METHANE "P-10"

GAS MULTIPLICATION

$$Q = n_0 e M$$

- Q = TOTAL CHARGE
- n_0 = ORIGINAL # OF ION PAIRS
- e = ELECTRON CHARGE
- M = MULTIPLICATION FACTOR

ASSUME PROCESS IS STRICTLY ELECTRON COLLISION (NOT PHOTOELECTRIC)

IN CYL. GEOMETRY MUST TAKE INTO ACCOUNT RADIAL E-FIELD

$$\ln(M) = \int_a^{r_c} \alpha(r)\, dr$$

r_c ≡ CRITICAL RADIUS OF THRESHOLD FIELD

α IS FUNCTION OF GAS TYPE & MAGNITUDE OF E-FIELD

$$\ln M = \int_{\mathcal{E}(a)}^{\mathcal{E}(r_c)} \alpha(\mathcal{E}) \frac{\partial r}{\partial \mathcal{E}} \, d\mathcal{E}$$

NOW INTRODUCE THE SHAPE OF THE ELECTRIC FIELD IN CYL. TUBES

$$\ln M = \frac{V}{\ln(b/a)} \int_{\mathcal{E}(a)}^{\mathcal{E}(r_c)} \frac{\alpha(\mathcal{E})}{\mathcal{E}} \frac{d\mathcal{E}}{\mathcal{E}}$$

ASSUME LINEARITY BETWEEN α & $\mathcal{E}$ "DIETHORN" EQUATION IS

$$\ln M = \frac{V}{\ln(b/a)} \cdot \frac{\ln 2}{\Delta V} \left(\ln\left(\frac{V}{pa \ln(b/a)}\right) - \ln K \right)$$

M = GAS MULTIPLICATION FACTOR
V = APPLIED VOLTAGE
a = ANODE RADIUS

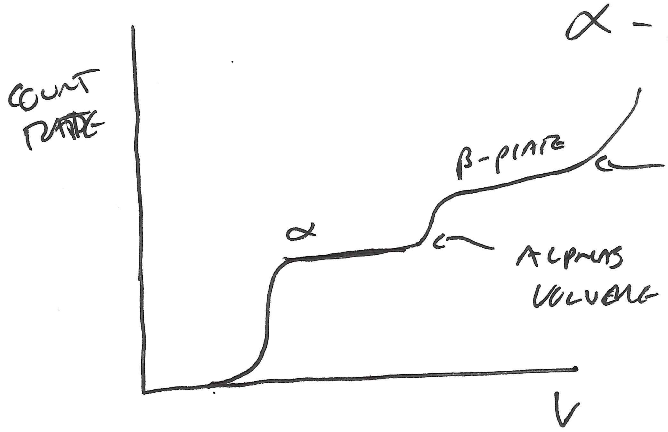
ΔV = POTENTIAL e^- MOVES BETWEEN SUCCESSIVE IONIZATION EVENTS
b = CATHODE RADIUS
p = GAS PRESSURE
K = MIN. VALUE WHICH $\mathcal{E}/p$ WHICH IONIZATION CAN'T OCCUR

FEW EXAMPLES OF PROPORTIONAL DETECTOR GAS MIXTURES

"P-10"	Ar(90%), CH_4 (10%)	$K = 4.8 \times 10^4$ V/cm/atm	ΔV: 23.6 eV
	He(96%), ISOBUTANE(4%)	$K = 1.48 \times 10^4$ V/cm.atm	ΔV: 27.6 eV

SELECTION OF OPERATING VOLTAGE & MIXED α-β

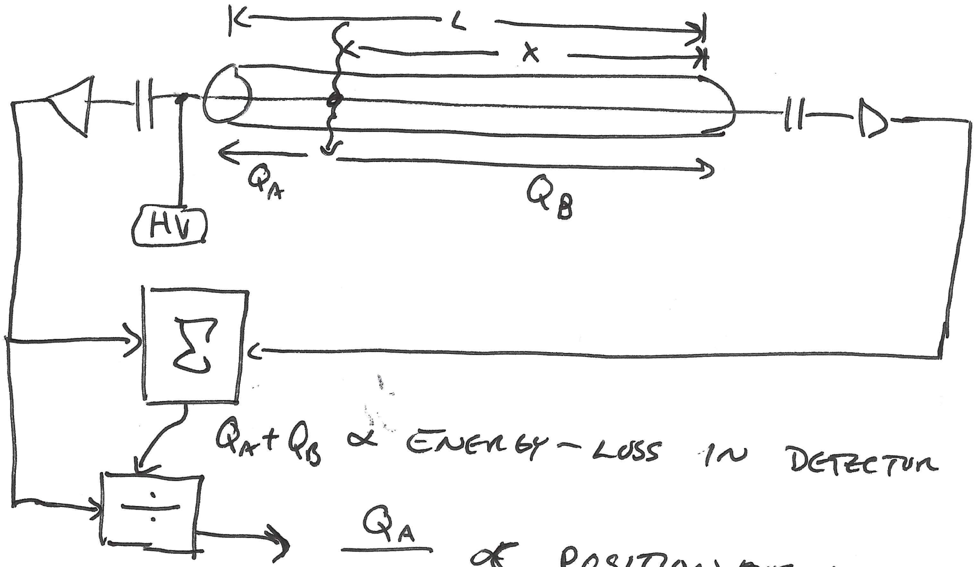
α - OF FIXED ENERGY.



← e^- GOES THRU THE DETECTOR, FEWER ION PAIRS, NEEDING HIGHER VOLTAGE

← ALPHAS GIVE ALL ENERGY INTO THE VOLUME OF THE DETECTOR GIVE LARGER SIGNAL

TIME SENSITIVE / POSITION SENSITIVE DETECTORS



$Q_A + Q_B \propto$ ENERGY-LOSS IN DETECTOR

$\frac{Q_A}{Q_A + Q_B} \propto$ POSITION ~~OF~~ THE PARTICLE TRACK

THE G-M DETECTOR GEIGER MUELLER IN 1928

- EVEN YET HIGHER ELECTRIC FIELD
- GAS MULTIPLICATION BUT FUNDAMENTALLY DIFFERENT.

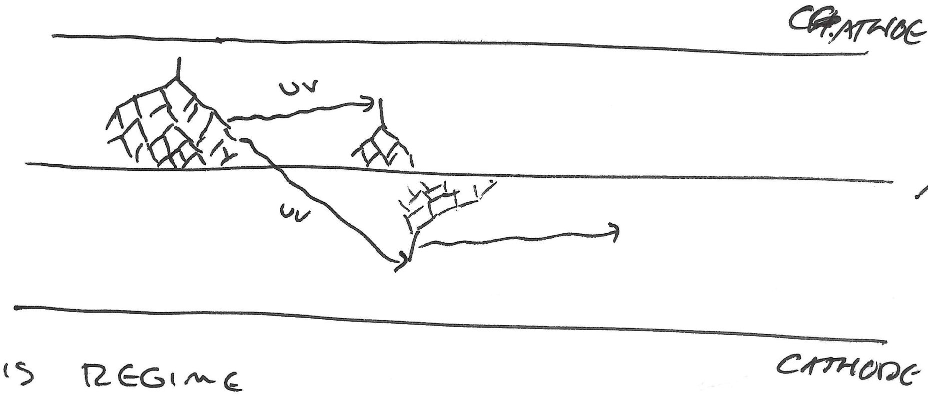
  UNLIKE PROPORTIONAL ONE e^- CAN TRIGGER MULTIPLE DIFFERENT AVALANCHES,
  HIGH ENOUGH VOLTAGE (E-FIELD), A SELF PROPAGATING CHAIN OCCURS, WITH AN EXPONENTIALLY GROWING # OF AVALANCHES OCCUR WITHIN A SHORT TIME.

  COLLECTIVE EFFECTS COME INTO PLAY & TERMINATE THIS "CHAIN REACTION"

- ALL PULSES FROM A GEIGER TUBE ARE OF THE SAME AMPLITUDE REGARDLESS OF THE NUMBER OF ORIGINAL ION PAIRS THAT INITIATE THE PROCESS.
- TYPICAL GEIGER TUBE PULSE GIVES ABOUT $10^9 - 10^{10}$ PAIRS

  OUTPUT PULSE IS LARGE.

GEIGER DISCHARGE



IN THIS REGIME

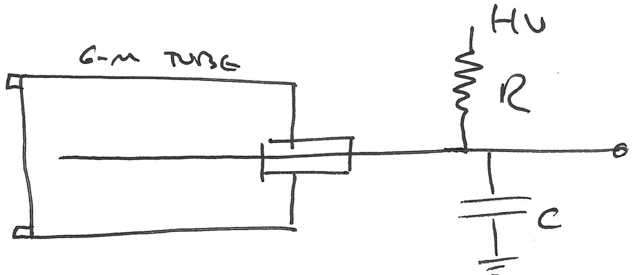
1 SINGLE e^- WILL CREATE MANY EXCITED GAS MOLECULES IN ADDITION TO THE SECONDARY ELECTRONS WHICH RECOMBINE WITHIN NANO SECONDS. THESE PHOTONS ARE KEY TO THE PROPAGATION OF THE AVALANCHING CHAIN REACTION.

- THE DISCHARGING CHAIN REACTION LEADS TO MANY AVALANCHES WHICH INITIATE AT RANDOM RADIAL & AXIAL POSITIONS. SECONDARY IONS ARE FORMED THROUGHOUT THE TUBE. MOBILITY OF THE IONS ARE SUCH THAT THEY FORM A BLANKET AROUND THE ANODE WHICH DROPS $\mathcal{E}$ THRESHOLD & REMAINDER OF ELECTRONS RECOMBINE.

- GASES AGAIN ARE SIMILAR TO PROPORTIONAL DETECTORS Ar + He, ELECTRONEGATIVES <u>MUST</u> BE AVOIDED. QUENCH GAS ARE USED

QUENCH GAS

AFTER PRIMARY DISCHARGE IS TERMINATED THE POSITIVE IONS SLOWLY DRIFT TO THE CATHODE/WALL. & NEUTRALIZED IN THIS PROCESS AN AMOUNT OF ENERGY EQUAL TO THE IONIZATION ENERGY OF THE GAS − CATHODE WORK FUNCTION IS NESSARY TO EXTRACT THE e^- IS LIBERATED, IF THIS EXCEEDS THE CATHODE WORK FUNCTION MORE ELECTRONS MAY BE LIBERATED, WHICH DRIFTS TO THE ANODE & STARTS THE PROCESS ALL OVER AGAIN... LEADING TO A CONTINUOUS DISCHARGE



EXTERNAL QUENCH BY RC TIME CONSTANT ~ MS, BUT NO GOOD FOR HIGH COUNTING RATES.

INTERNAL QUENCH. A GAS WITH A LOWER IONIZATION POTENTIAL & MORE COMPLEX MOLECULAR STRUCTURE THAN THE PRIMARY GAS. 5~10%. QUENCH OCCURS VIA CHARGE TRANSFER: FORMED POSITIVE IONS COLLIDE WITH THESE ~~[illegible]~~ OTHER MOLECULES OF LOWER IONIZATION POTENTIAL. AT SUFFICIENT CONCENTRATION ONLY THE CHARG-TRANSFER GASES WILL MAKE IT TO THE CATHODE.

TYPICAL QUENCH GASES ARE ~~ETHYL~~
ETHYL ALCOHOL + ETHYL FORMATE

QUENCH GAS IS ~~CONSUMED~~ DISSASOCIATED IN THE PROCESS
+ IS SLOWLY CONSUMED.

TYPICAL LIFETIME IS 10^9 COUNTS

~~THE~~ HALOGEN GASES, HOWEVER (CHLORINE, BROMINE)
WILL RECOMBINE AT A LATER TIME, SUGGESTING AN
INFINITE LIFE G-M TUBE.

OTHER EFFECTS LIMIT LIFE OF TUBES.

- REACTION PRODUCTS IN THE DISCHARGE
- DAMAGE TO ANODE SURFACE BY DEPOSTION OF POLYMERIZED REACTION PRODUCT,

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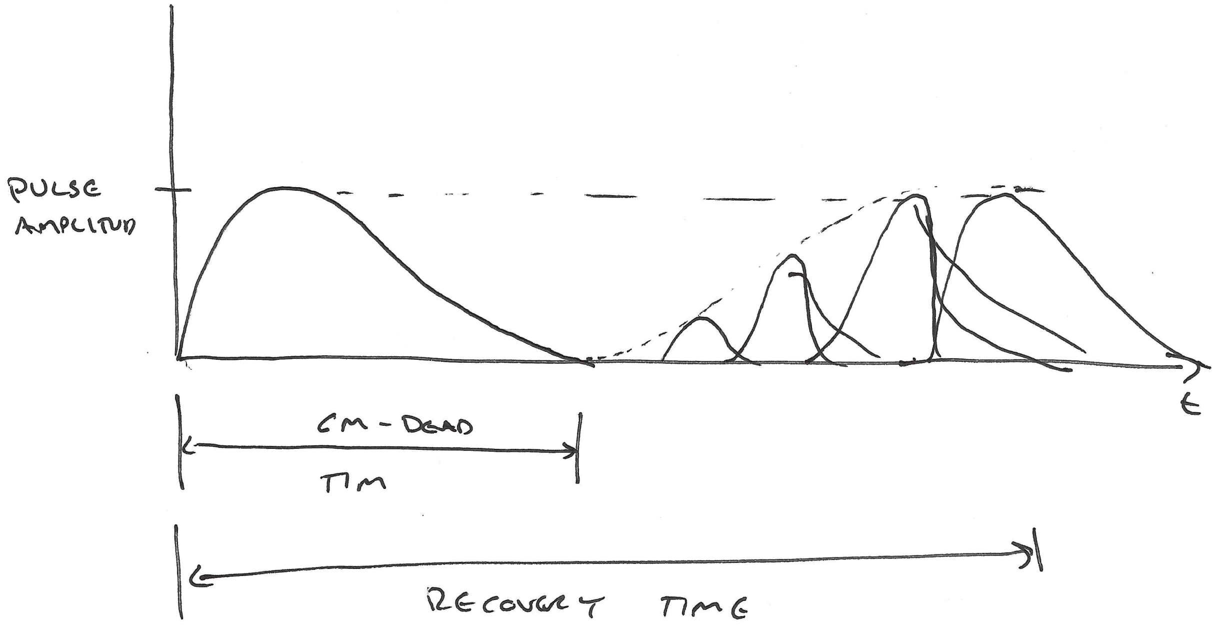
TIME BEHAVIOR

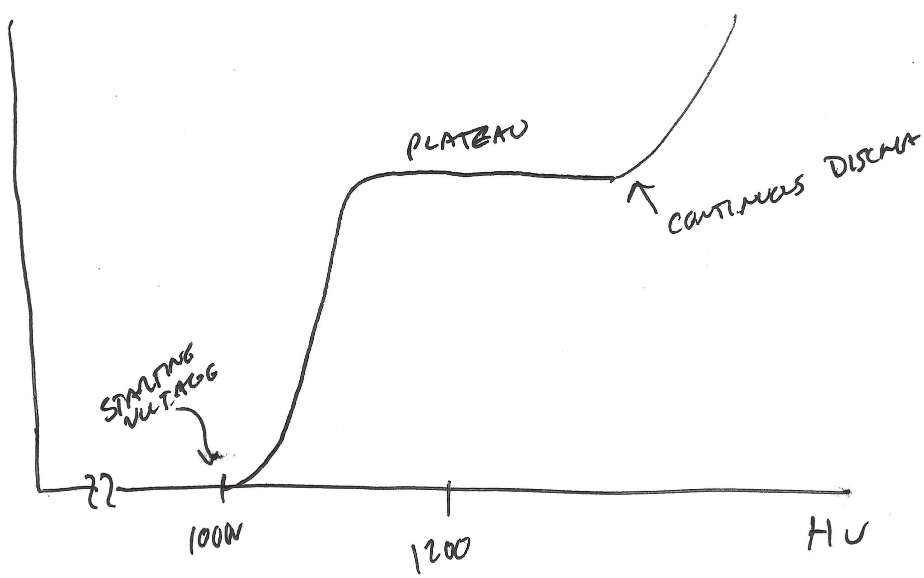
- RISE TIME ON ORDER OF 1μSEC
- RECOVERY TIME ~ 100μSEC

<u>DEAD TIME</u> IN GEIGER TUBE

IMMEDIATELY FOLLOWING THE GEIGER DISCHARGE THE ELECTRIC FIELD HAS BEEN REDUCED BELOW THE CRITICAL POINT BY POSITIVE SPACE CHARGE. IF ANOTHER IONIZING EVENT OCCURS UNDER THIS CONDITION A SECOND PULSE WILL NOT BE OBSERVED



~~PLATEUAG~~ PLATEAU



G-M SURVEY METERS

PORTABLE GAMMA-RAY MONITORING DETECTORS HAVE A METER THAT READS IN DOSE-RATE.

PULSE RATE IS TAKEN AS AN INDICATION OF INTENSITY OF GAMMA RAY EXPOSURE BUT CAN HAVE FACTORS

IN CONTRAST TO THE ION CHAMBER THE COUNT RATE BEARS NO FUNDAMENTAL RELATION TO THE GAMMA EXPOSURE RATE.

SCINTILLATION DETECTORS

DETECTION OF RADIATION BY PRODUCING LIGHT IS OLDEST FORM OF DETECTION. + IS STILL USED BROADLY

THE SCINT. MATERIAL SHOULD INCLUDE

- CONVERT K.E. OF CHARGED PARTICLES INTO DETECTABLE LIGHT W/ HIGH SCINT. EFFICIENCY
- CONVERSION SHOULD BE LINEAR. LIGHT PROPORTIONAL TO DEPOSITED ENERGY
- SCINT MATERIAL SHOULD BE TRANSPARENT TO λ OF ITS OWN LIGHT EMISSION FOR EFFECTIVE COLLECTION
- DECAY TIME OF LUMINESCENCE SHOULD BE FAST
- EASY TO MANUFACTURE + COUPLE TO LIGHT SENSITIVE INSTRUMENTS