DETECTING RADIATION

- WHAT MAKES UP A DETECTOR?

- SINGLE PARTICLE: α, β, γ, n etc

MUST INTERACT IN ONE OF THE WAY WE'VE DISCUSSED.

- THE INTERACTION / STOPPING TIME MUST BE SMALL (NANO OR PICO SECONDS) ~ INSTANTANEOUS

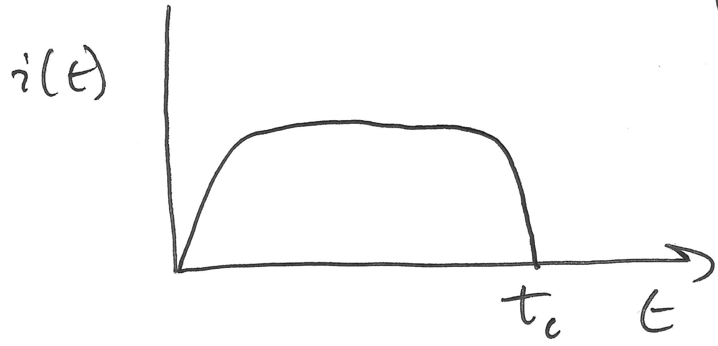
- INTERACTION INSIDE THE VOLUME OF THE DETECTOR IS THE APPEARANCE OF A GIVEN AMOUNT OF ELECTRIC CHARGE

$$Q \text{ AT TIME } t = 0$$

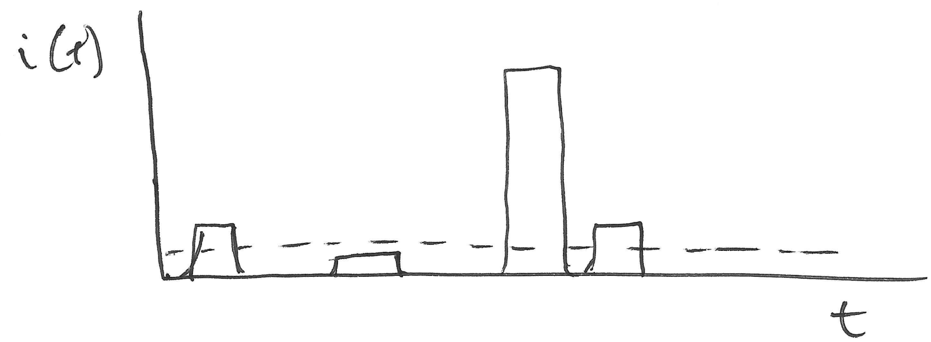
- CHARGE IS COLLECTED BY THE IMPOSITION OF AN ELECTRIC FIELD

- TIME TO COLLECT CHARGE VARIES GREATLY BETWEEN DETECTOR TYPES. UP TO ~ms

(THIS IS ~~DUE~~ REL. TO THE MOBILITY ~~OF~~ OF CHARGE CARRIERS & DISTANCE THEY MUST TRAVEL



$$\int_0^{t_c} i(t)\,dt = Q$$

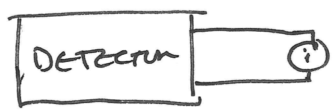


MODES OF OPERATION

~~PULSE MODE~~

CURRENT MODE
PULSE MODE
MEAN SQUARE VOLTAGE — "CAMPBELLING" — MOSTLY ENCOUNTERED IN REACTORS, JOIN REACTOR CLUB TO LEARN MORE

(A) CURRENT MODE:



FIXED RESPONSE TIME T, WILL GIVE TIME-DEPENDANT RECORD

$T \sim$ SECONDS

$$I(t) = \frac{1}{T}\int_{t-T}^{t} i(t')\,dt'$$

BY ADJUSTING T LARGER, MINIMIZE STATISTICAL FLUCTUATIONS BUT SLOWS OR IS "BLIND" TO RAPID ~~C~~HANGES IN ACTUAL RATE

AVG CURRENT PER EVENT IS GIVEN BY AVG EVENT RATE × Q / TIME

$$I_0 = rQ = r\frac{E}{W}q$$

r = ~~~~ EVENT RATE

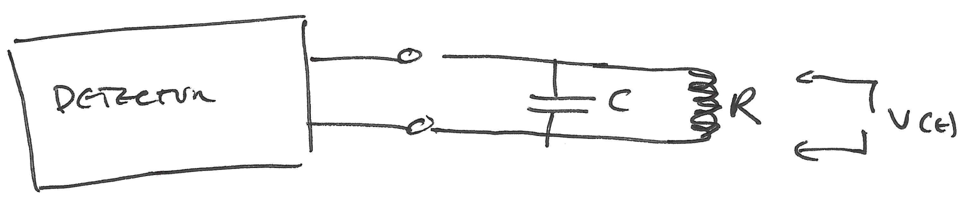
$Q = \frac{Eq}{W}$ CHARGE PRODUCED PER EVENT

W = AVERAGE ENERGY REQUIRED TO PRODUCE e^--ION PAIR

$q = 1.6\times10^{-19}$ C

- HIGH RANGE INSTRUMENTS

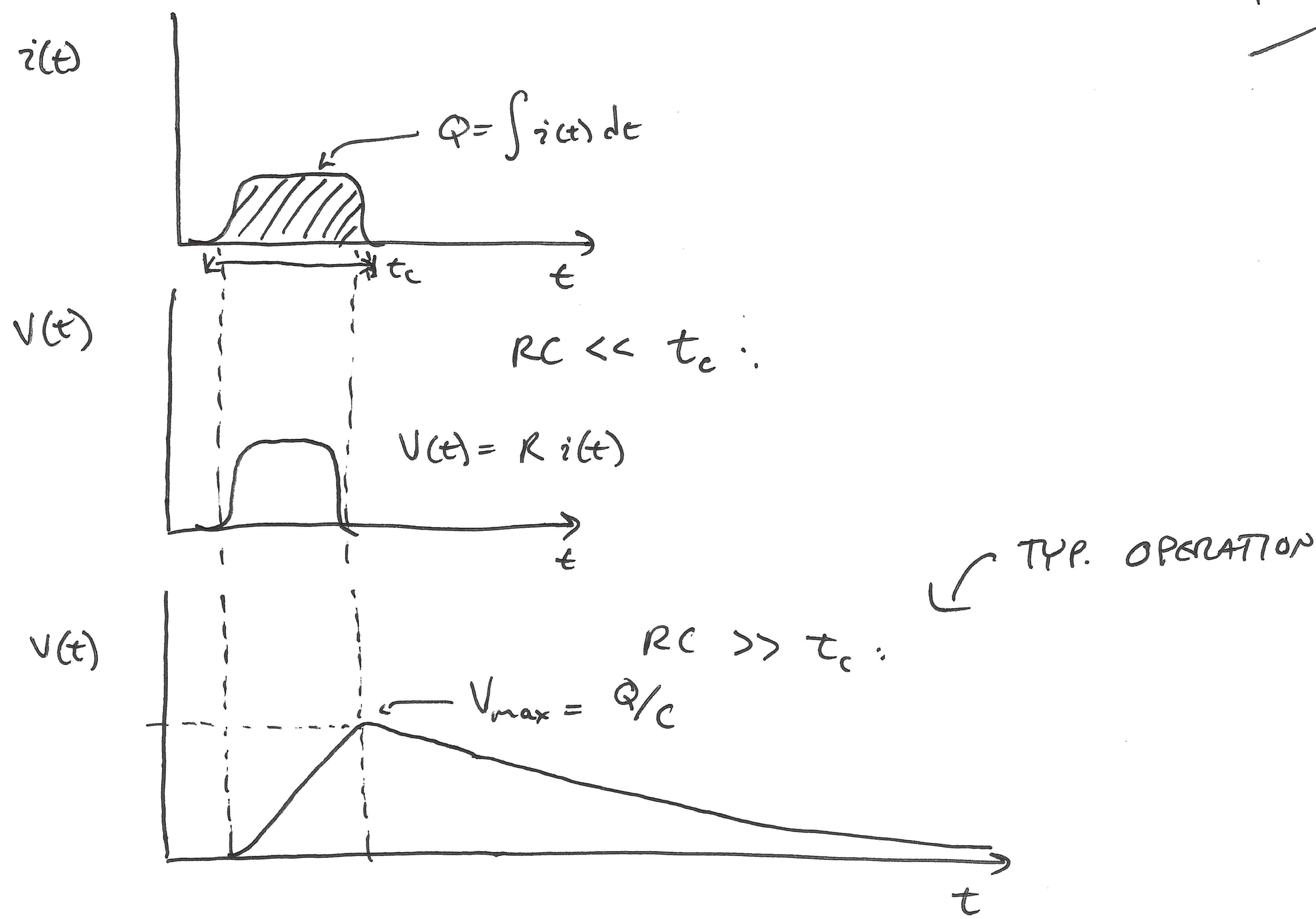
(B) PULSED MODE



TIME CONSTANT IS GIVEN BY R, C $\tau = RC$

- SMALL RC GIVES DETECTORS LIMITED RESPONSE TIME

- LARGE RC, LITTLE CHARGE WILL FLOW THROUGH RESISTOR ~~WILL~~ BUILD UP ON CAPACITOR



SINCE C IS FIXED, AMPLITUDE OF SIGNAL PULSE IS DIRECTLY PROPORTIONAL TO TO CHARGE GENERATED IN THE DETECTOR.

- OUTPUT IS A STRING OF PULSES, REPRESTING A SINGLE INTERACTION.

~~DET~~

DETECTION EFFICIENCY

- ALL DETECTORS WILL GIVE RISE TO AN OUTPUT PULSE FOR EACH QUANTUM OF RADIATION THAT INTERACTS WITH IT.

  - THIS IS SIMPLE FOR α, + β, THAT INTERACT IMMEDIATELY IN THE DETECTOR

  - EASY TO ARRANGE A SYSTEM THAT SEES EVERY α + β WHICH IS SAID TO HAVE 100% EFFICIENCY.

  - NOT SO TRUE FOR γ OR n, WHICH ~~REQUIRE~~ CAN TRAVEL A LONG DISTANCE A SIGNIFICANT INTERACTION BEFORE

~~BUT CAN TRA~~

$$\epsilon_{ABS} = \frac{\text{\# of PULSES RECORDED}}{\text{\# of RADIATION QUANTA EMITTED}}$$

WHICH CAN BE BROKEN INTO TWO SUB-EFFICIENCIES

1. INTRINSIC EFF OF DETECTOR:

$$\epsilon_{INT} = \frac{\text{\# PULSES RECORDED}}{\text{\# OF QUANTA INCIDENT ON DETECTOR}}$$

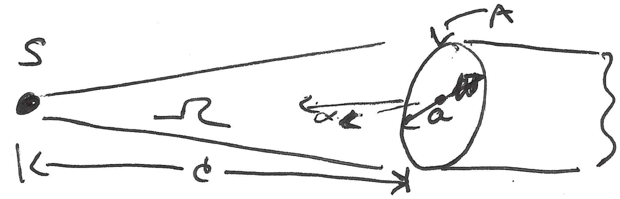
2. GEOMETRY EFFICIENCY

ASSUMING AN ISOTROPIC SOURCE;

~~$\epsilon_{ABS} = \epsilon_{INT}$~~ $\epsilon_{INT} = \epsilon_{ABS} \left(4\pi/\Omega\right)$

WHERE Ω IS THE SOLID ANGLE OF ~~SEEN BY THE DETECTOR~~ THE DETECTOR SEEN FROM THE ACTUAL SOURCE POSITION.

EXAMPLE



A DETECTOR WITH KNOWN EFFICIENCY CAN BE USED TO MEASURE ABSOLUTE ACTIVITY OF A RADIOACTIVE SOURCE:

ASSUMES A POINT SOURCE

ϵ_{int} ≡ DETECTOR EFF

N ≡ # OF EVENTS

ISOTROPIC, NO ATTENUATION

S ≡ # OF RADIATION QUATA EMITTED DURING MEASUREMENT PERIOD

$$S = N \frac{4\pi}{\epsilon_{int}\,\Omega}$$

Ω IS SOLID ANGLE IN STERADIANS

$$\Omega = \int_A \frac{\cos\alpha}{r^2}\,dA$$

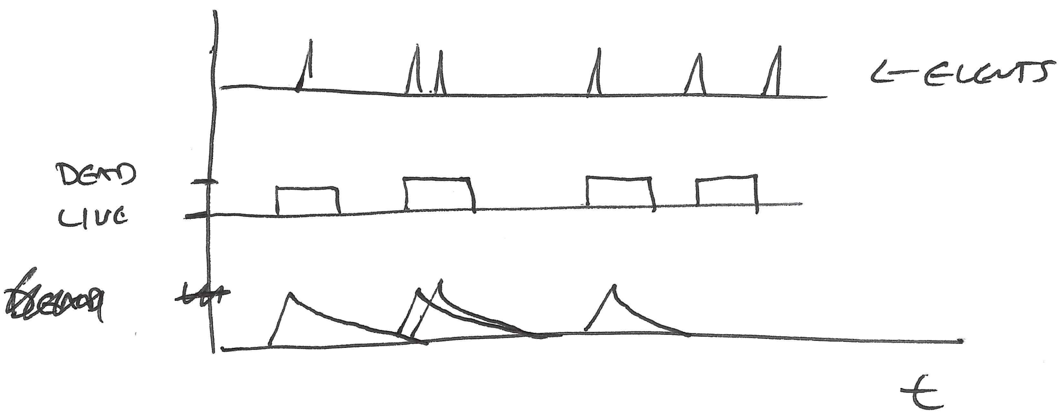
COMMON CASE OF POINT SOURCE ALONG AXIS OF A RIGHT CYLINDRICAL DETECTOR

$$\Omega = 2\pi\left(1 - \frac{d}{\sqrt{d^2+a^2}}\right)$$

FOR $d \gg a$

$$\Omega \cong \frac{A}{d^2} = \frac{\pi a^2}{d^2}$$

DEAD TIME / LIVE TIME



n = TRUE INTERACTION RATE

m = RECORDED INTERACTION RATE

τ = DEAD TIME

FRACTION OF ALL TIME DETECTOR IS DEAD IS JUST

$m\tau$

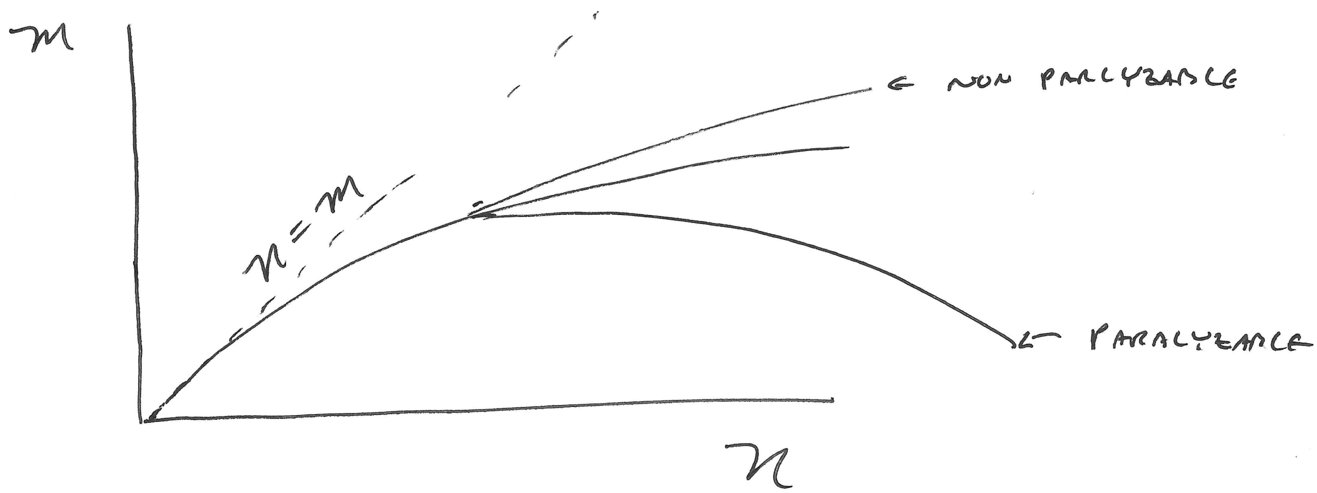
RATE A WHICH REAL EVENTS ARE LOST

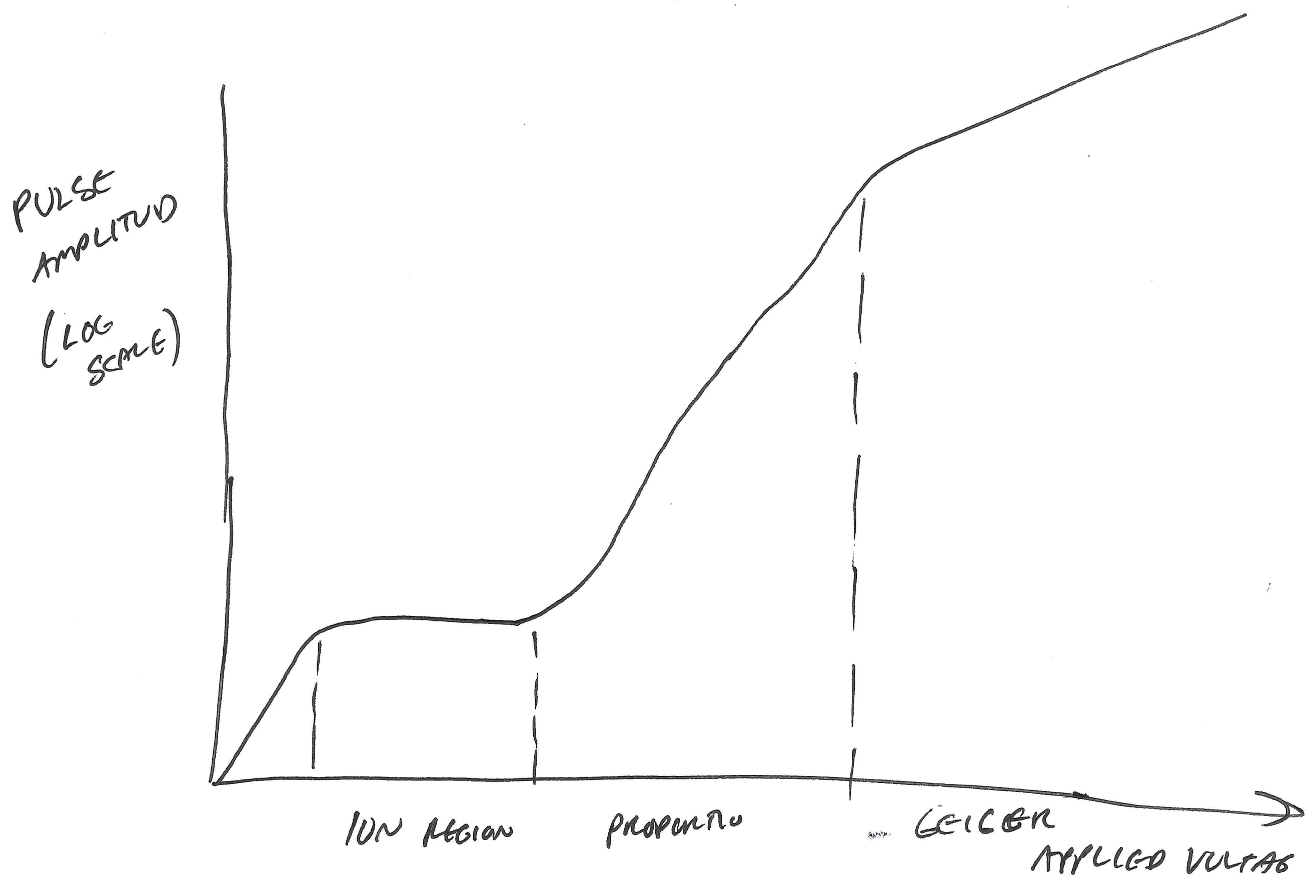
$nm\tau$

$n - m$ IS ALSO THE LOSS RATE OF REAL EVENTS

$n - m = nmt$ SOLVE FOR n

$$n = \frac{m}{1 - mt}$$

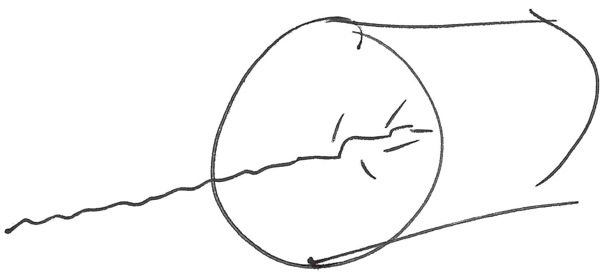



PULSE AMPLITUD
(LOG SCALE)
ION REGION
PROPORTIO
GEIGER
APPLIED VOLTAG

IONIZATION (ION) CHAMBERS

REFERS TO GAS FILLED DETECTOR (IN SOLIDS IT e^--HOLE PAIRS)

"SIMPLEST" OF THE GAS FILLED DETECTORS



AGAIN BOTH EXCITATION & IONIZATION OCCUR.

AFTER NEUTRAL MOLECULE IS IONIZED, THE RESULTING POSITIVE ION & FREE e^- ARE CALL AN "ION-PAIR"

VALUES OF ENERGY DISSIPATION PER ION PAIR (THE W-VALUE) FOR SEVERAL GASES

GAS	eV/ion pair: FAST e^-	eV/ion pair: α
Ar	26.4	26.3
AIR	33.8	35.1
CH_4	27.3	29.1

} 30–35 eV/pair

THEREFORE, INCIDENT 1-MEV

PARTICLE IF COMPLETELY STOPPED WILL

CREATE ~ 30,000 ION PAIRS

SELECTION OF GAS IS CRUCIAL TO

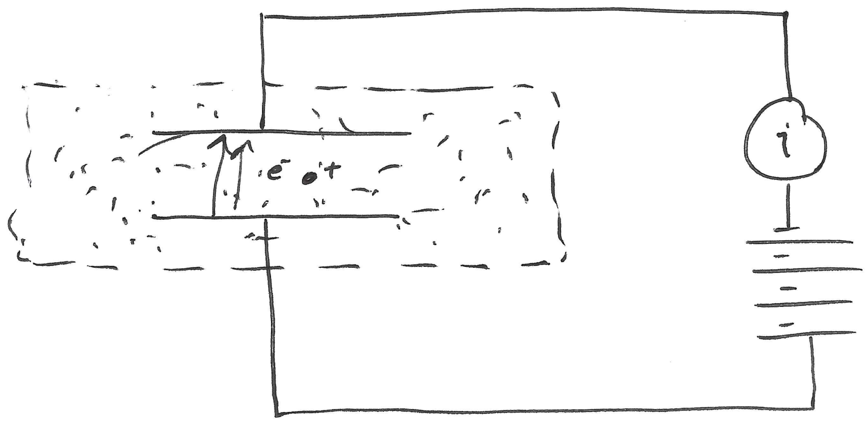
DETECTOR PERFORMANCE

OXYGEN WILL FORM A NEGATIVE ION,

SO ~~SECOND~~ FREE e^- FLOWING CAN

REDILY BE CAPTURED.

CHARGE MOBILITY



APPLY $\bar{E}$-FIELD TO REGION WHERE ION PAIRS EXIST IN THE GAS, + E-FIELD WILL PULL THEM AWAY FROM THEIR POINT OF ORIGIN. A COMBINATION OF THERMAL + DRIFT VELOCITIES.

FOR IONS IN A GAS, DRIFT VELOCITY IS ~~CAN BE~~ ~~E~~

$$v = \mu \frac{\mathcal{E}}{P}$$

- v ← DRIFT VELOCITY
- μ ← MOBILITY
- $\mathcal{E}$ ← ELECTRIC FIELD STRENGTH
- P ← GAS PRESSURE

MOBILITY IS FAIRLY CONSISTENTLY $1 \sim 1.5 \times 10^{-4}\ m^2 \cdot atm / V \cdot s$

$\sim$ E FIELD $10^4\ V/m \rightarrow v \approx 1\ m/s$

FREE e^- ARE MUCH DIFFERENT.

- A MOBILITY ~ 1000 x FASTER.

∴ COLLECTION TIMES ~ μsec

IONIZATION CURRENT

IN $\vec{E}$-FIELD, e^-· ION PAIRS CREATES A CURRENT

DURING STEADY STATE IRRADIATION THE RATE OF FORMATION OF ION PAIRS IS CONSTANT.

THIS WILL BE EXACTLY BALANCED BY THE RATE AT WHICH THE ION PAIRS ARE LOST, VIA RE-COMBINATION OR DIFFUSION OR MIGRATION OUT OF THE VOLUME.

UNDER CONDITIONS THAT RE-COMBINATION IS INSIGNIFICANT & CHARGE IS COLLECTED: IONIZATION CURRENT.

CURRENT - VOLTAGE CHARACTERISTICS

AS VOLTAGE IS INCREASED, $\vec{E}$-FIELD SEPARATES ION PAIRS MORE RAPIDLY & RE-COMBINATION IS DIMINISHED.

THEN IT "SATURATES" BECAUSE ALL ION PAIRS ARE COLLECTED.

ION CHAMBERS ARE USED TO MEASURE DOSE. ~~FOR~~ PHOTONS AIR ION CHAMBERS ARE GOOD FOR THIS