Platinum resistance

- Platinum resistance

  Very stable and reproducible, wide T range (~ -200°C to 1000°C)

  T coefficient ~ +0.4%/°C

  Bulky and expensive for some applications (~ £2-3)

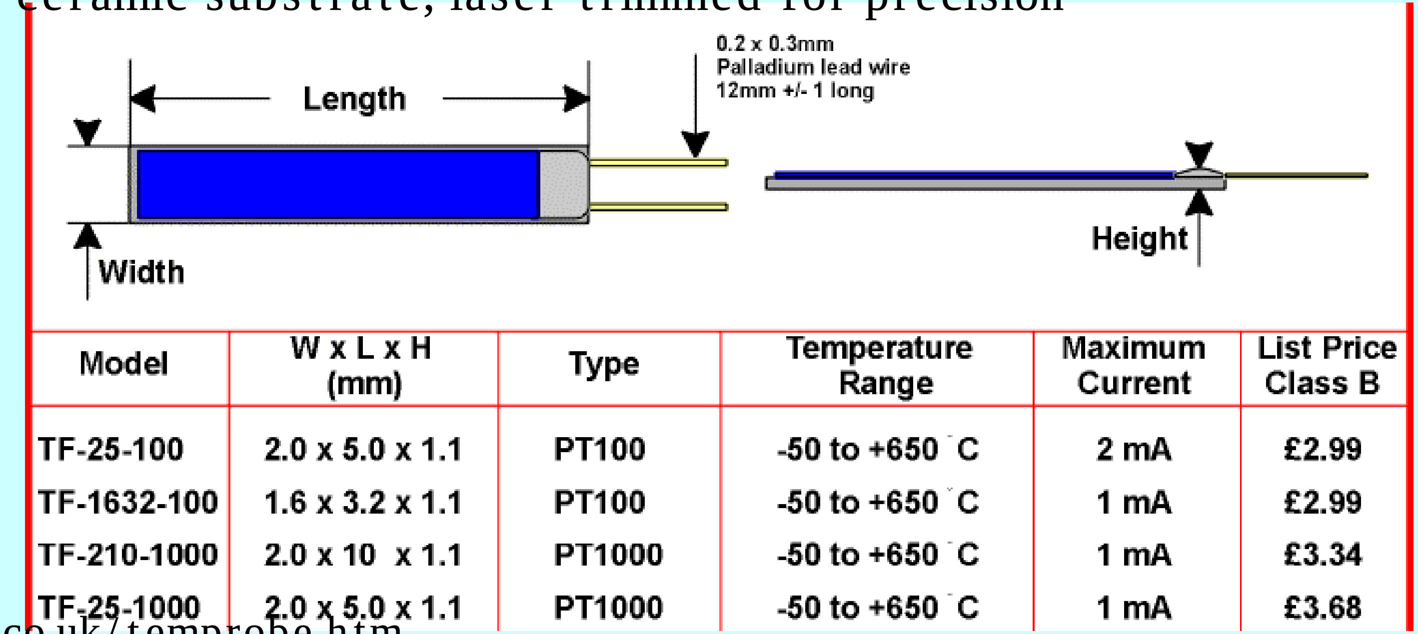
  need wires (R) or local I/V circuit

- Standard value R = 100Ω (PT100)

  eg Pt film deposited on ceramic substrate, laser trimmed for precision

  also

  wirewound versions



Model	W x L x H (mm)	Type	Temperature Range	Maximum Current	List Price Class B
TF-25-100	2.0 x 5.0 x 1.1	PT100	-50 to +650 °C	2 mA	£2.99
TF-1632-100	1.6 x 3.2 x 1.1	PT100	-50 to +650 °C	1 mA	£2.99
TF-210-1000	2.0 x 10 x 1.1	PT1000	-50 to +650 °C	1 mA	£3.34
TF-25-1000	2.0 x 5.0 x 1.1	PT1000	-50 to +650 °C	1 mA	£3.68

eg http://www.kalestead.co.uk/temprobe.htm

Other temperature transducers

- Exotics each a specialised subject

Non-contact measurements	infra-red sensors based on, eg, CCDs
Ultra-low temperature	~ 0K

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Ionisation sensors

- Indirect

  produce a signal which must be further converted to an electrical signal

  mostly light: scintillators, Cerenkov radiation, transition radiation (x-ray)
  acoustic

- Direct

  produce a directly measurable electrical signal

  may still require amplification

  gaseous and semiconductor devices dominate

Scintillators

- Light emitted following ionisation in a transparent material

  Typical $I(t) \sim I_0 e^{-t/\tau}$ sometimes several components $I_1, I_2, \ldots \tau_1, \tau_2, \ldots$

  Wavelength of emission determines requirement on photosensor type

  along with signal speed requirement

  eg. $\tau > \mu s$ => count rates << MHz

  $\tau \sim ns$ => count rates >> MHz

- Two main material types - contrasting mechanisms

  Inorganic scintillators

  result of crystalline structure of material

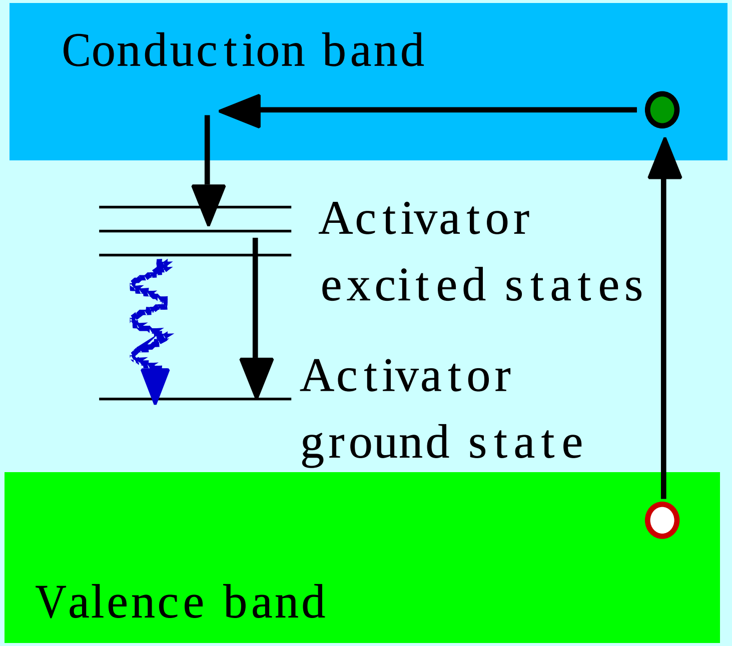
  large band gap => insulators

  Organic scintillators

  molecular property (independent of state - liquid or solid)

Inorganic scintillators

- ionisation excites electrons from valence to conduction band
  - de-excitation via photon emission
    - or radiationless transition



- Large band gap => slow process
  - low transition probability
  - short wavelength ($E_\gamma = E_{bandgap}$)

- Impurities add centres (traps) in band-gap
  - increase transition rates
  - suitable doping can also increase light output
    - *eg thallium in NaI*
  - holes trapped at activator sites
    - *recombination with* e^- => *photon*
  - smaller energy gap increases wavelength
    - *crystal also transparent to scintillation photons*

Inorganic scintillator characteristics

- high light output but relatively slow (~µsec), good linearity
  - dense, high atomic number (Z) material
    - *good for for e-/gamma ray detection*
  - expensive - very good crystals required, usually large.
    - *raw material, growing, cutting and polishing of large crystals*
  - many require specialised photosensor
    - *blue or UV emission*
  - some undoped materials offer advantages of speed and radiation hardness
    - *drawback of lower light yield*
  - care is needed in material preparation
    - *performance can be badly affected by (wrong!) impurities*
  - some crystals can be coated on photosensors
    - *convenient for efficient sensor systems but limits thickness*

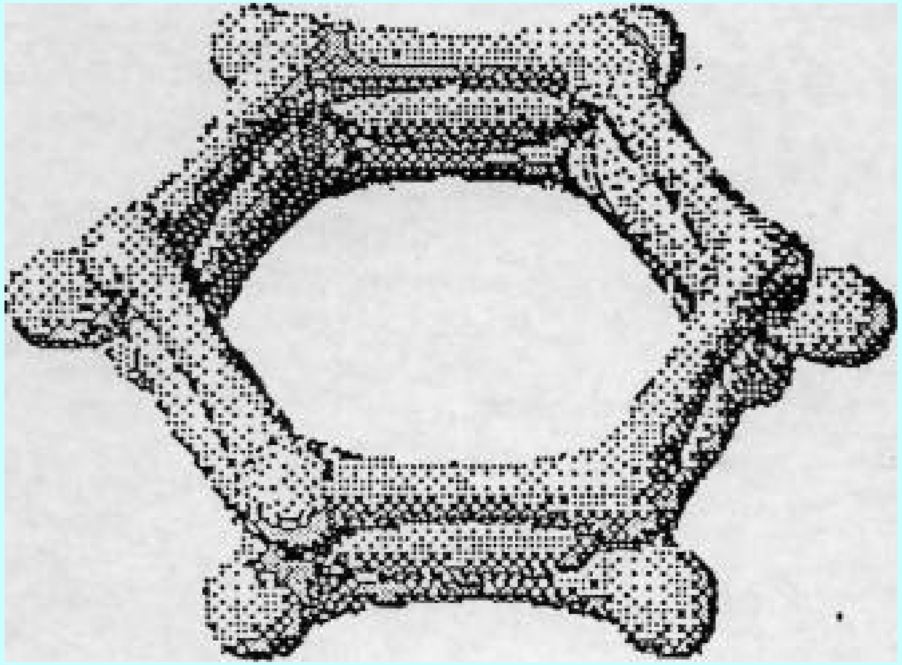
- applications
  - medical imaging (eg. gamma camera, ~MeV photons from radio-isotopes)
  - astronomy and particle physics detectors

Examples of inorganic scintillators

		λ_{peak} (nm)	relative light output	time constant (µsec)	Density g.cm^{-3}	
Sodium iodide	NaI(Tl)	410	1	0.23	3.7	High light output, hygroscopic, large crystals fragile
Caesium iodide	CsI(Tl)	540	1.71	0.68 (64%) 3.34 (36%)	4.5	Non hygroscopic. wavelength match Si photodiodes
Bismuth germanate	BGO $Bi_4Ge_3O_{12}$	480	0.22	0.3	7.1	High Z, low light output
Barium fluoride	BaF_2 (fast) BaF_2 (slow)	220 310	0.05 0.16	0.0006 0.62	4.9	Fast, two components, in UV low light output, rad hard
Cerium fluoride	CeF_3	310 340	0.005 0.027	0.12	6.16	low light output, radiation hard
GSO	Gd_2SiO_5 (Ce doped)	440	0.24	0.056 (90%) 0.4 (10%)	6.71	Fast, rad tolerant
YAP	$YAlO_3$ (Ce doped)	440	0.47	0.027	5.37	Fast, good mechanical properties

Organic scintillators - hydrocarbon molecules

- Based on excited states of carbon atom, typically electron orbitals of benzene ring (C=C bonds)



imagine π orbitals as figures of eight binding two benzene rings
but free to move around ring

quasi-free electrons confined to molecular perimeter (length l)

1-d Schrodinger equation => $\psi(x) = \psi(x+l)$

$E_n = n^2h^2/2me^2l^2$ spectrum of energy levels

In practice more complex, vibrational states give fine structure

range of singlet & triplet states gives both long and short time constants

Organic scintillator spectra

- Complex spectrum of energy levels

major S & P states accompanied by vibrational sub-levels - ΔE ~ 0.16eV

ionisation raises electron to excited state

fast decay to S_{00}

followed by

radiative decay to ground states

= fluorescence ~nsec

ΔE_{S1-S2} ~ few eV

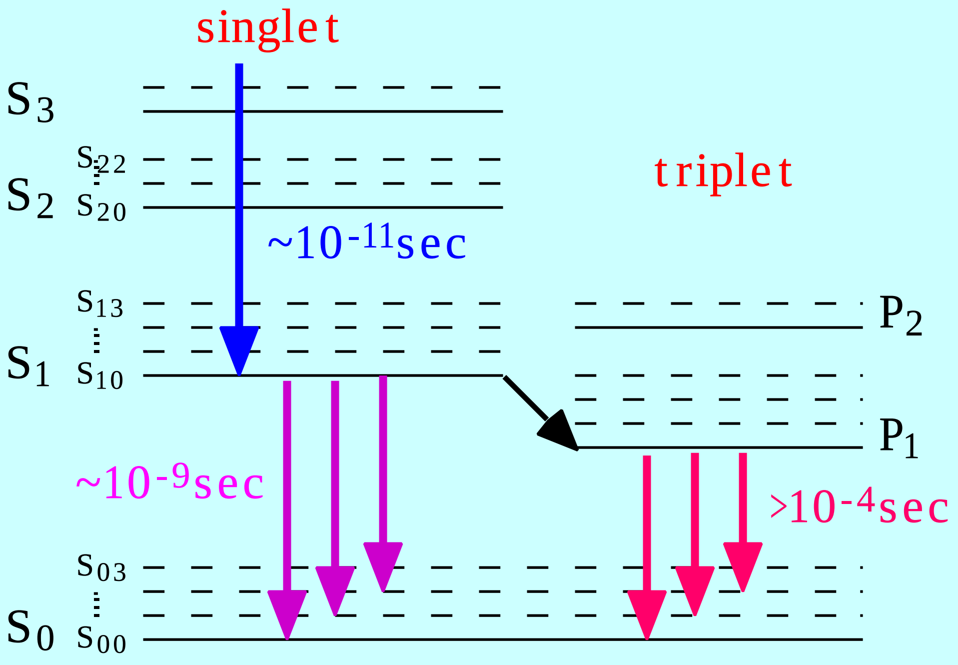
or non-radiative decay S-P

slow and less likely

radiative decay P-S

phosphorescence ~msec

can also have "delayed fluorescence" from P state thermally excited to S_1



Organic scintillator characteristics

- Solid base material (plastic) doped with fluor - but can be liquid scintillator

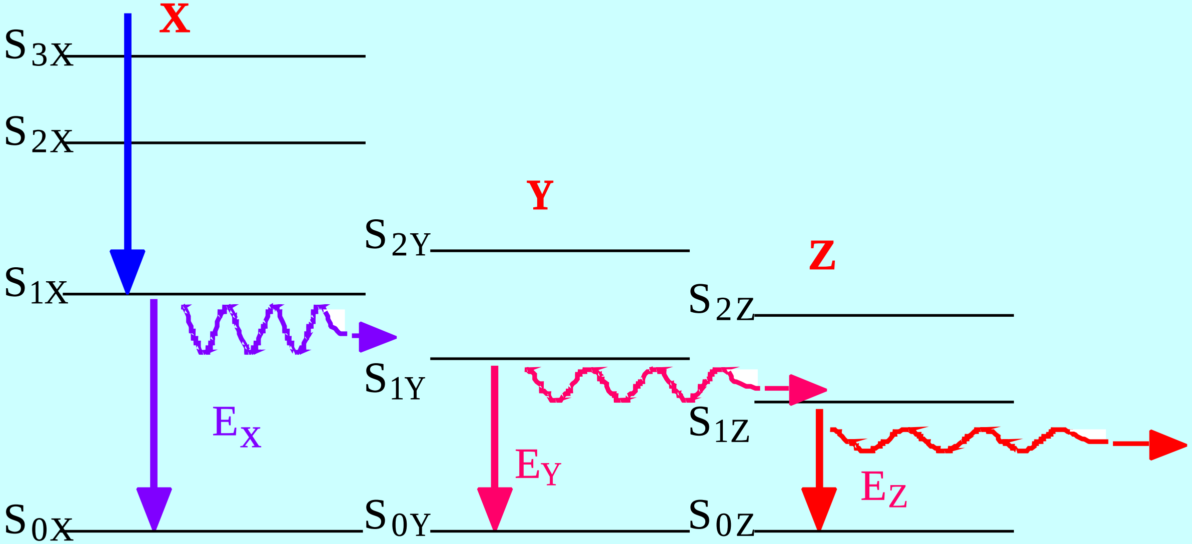
  inexpensive, low Z (primarily C, H, O)

- Primary fluor likely to be very short wavelength

  not usually matched to available sensors

  re-absorption by secondary fluor shifts light to longer, detectable wavelength

  overlapping spectra required



Initial photon is absorbed within a few mm, then re-emitted

plastic doped with wavelength shifters converts far-UV light emission to convenient part of spectrum

can be also used to transport light - eg in fibre or plastic light guide

- multi-step process, including efficiency & attenuation

  low light output cf inorganic scintillators, and non-linear

Examples of organic scintillators

Primary fluor	peak wavelength nm	time constant ns	relative light output cf NaI
Napthalene	348	96	0.12
Anthracene	440	30	0.5
p-terphenyl	440	5	0.25
PBD	360	1.2	
Wavelength shifter			
POPOP	420	1.6	
bis-MSB	420	1.2	
BBQ	500		

Originally discovered in pure natural materials like anthracene but chemists have produced a wide range of binary and tertiary systems

Chemistry of fluors determines λ and time constants

Typical commercial products (Nuclear Enterprises)

	peak wavelength	trise ns	tdecay ns	Attenuation length cm
NE110	434	1.0	3.0	400
NE104	406	0.6	1.8	120
NE108	535		~15	

Applications

fast detection but without energy measurement, Time of Flight

astro-particle physics, environmental monitoring, nuclear detection

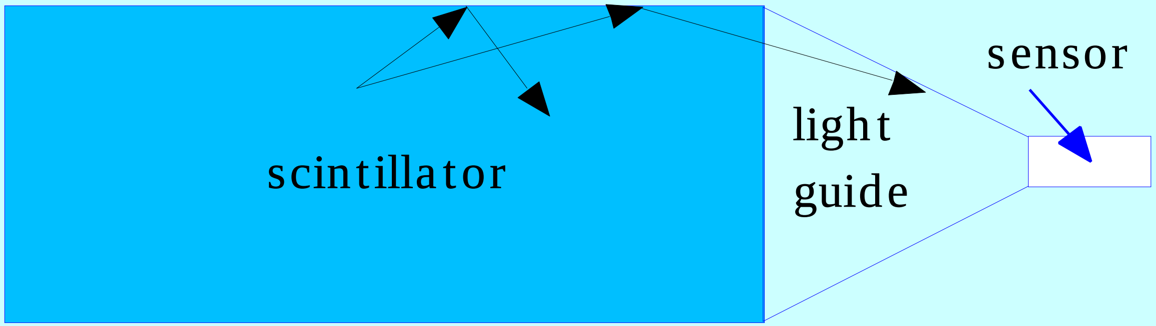
Light collection from scintillators

- Primary and subsequent emission will be isotropic

very often require light to be collected on a area much smaller than scintillator

on average, equal light intensity per face

make use of total internal reflection at surface to enhance collection at sensor

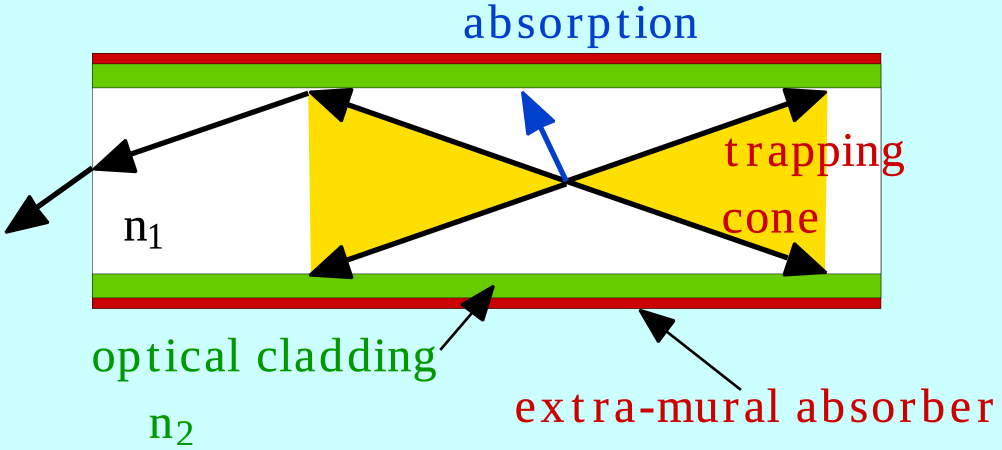


eg. loosely wrap scintillator so it has an air-scintillator boundary

for critical applications trace rays to optimise geometry

also used in scintillating optical fibres

same principle for all optical fibre light transmission



Scintillators - summary

- Inorganic

  based on crystals

  important for accurate energy measurement and stopping power

- Organic

  molecular property of hydrocarbons

  important for speed and low cost

- Long term behaviour

  Both types of scintillator are damaged slowly by radiation

    inorganic - atomic displacement creates new band gap energy levels

    giving attenuation of light

    organic - breaking of chemical bonds alters chemistry

    reduction of light output and attenuation

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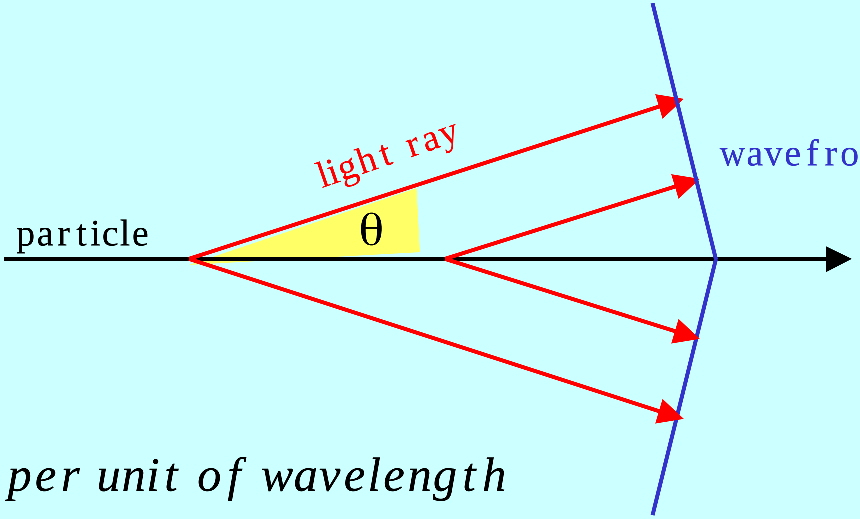
Cerenkov radiation

- when a **charged** particle travels faster than $c_{material}$ in a transparent medium
  - light emitted on surface of a cone, angle θ
    - $\cos\theta = 1/\beta n$
  - $\beta = v/c$ $\quad$ n = *refractive index*



- Characteristics
  - much of light in visible region of spectrum
    - *No of Cerenkov photons per unit thickness per unit of wavelength*
    - $d^2N/dxd\lambda \sim \sin^2\theta/\lambda^2$
  - significant sensitivity gain if extend photon observation to shorter wavelengths
  - since light output = f(β) possible to distinguish particles of different mass
  - suitable sensor required
    - *any photon detector with sufficient sensitivity in visible-UV*
- Applications
  - identification of particles in accelerator beams and experiments
  - ultra-high energy particle detection in atmospheric air showers