Experimental Particle Physics 2020-2021

Exam questions

Please be aware that logging in (opening the test) for the exam means the same as showing up for an exam; your presence will be recorded and your efforts will be graded.

Question 1 (2 points)

Assuming that charge collection is complete and that electronic noise is negligible, find the expected energy resolution (in percent) of a germanium detector for the 0.662 MeV gamma rays from ^{137}Cs.

Question 2 (4 points)

The intrinsic detection efficiency for a gas-filled counter (proportional counter or Geiger-Mueller tube) when used with medium-energy gamma rays (say 1 MeV) will depend on the counter wall thickness as shown in figure 1.

- Explain the general shape of this curve and how gamma-rays are detected by such counter **(1.5 points)**.
- Give an order-of-magnitude estimate for the optimum wall thickness t_m and relate it to basic physical properties **(2.5 points)**.

Please assume that the counter has structure as shown in figure 2. Walls are made of aluminium (ρ = 2.7 g/cm^3, Z = 13). The counter is filled with air at the pressure of 0.1 bar and therefore, gamma-rays mainly interact with the walls.

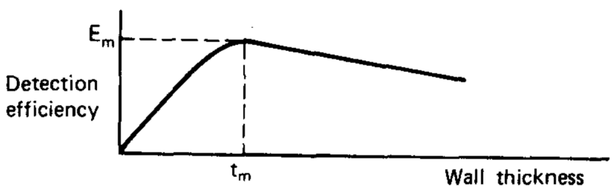

Figure 1.

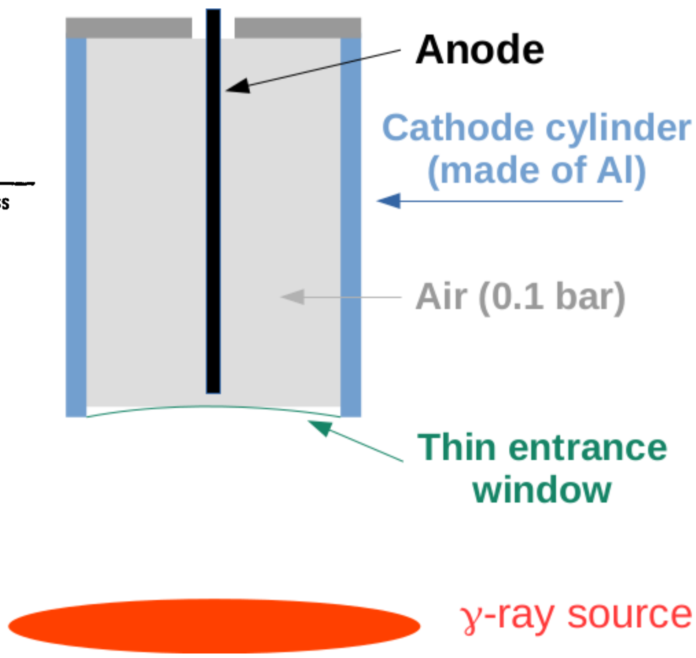

Figure 2.

Question 3 (4 points)

Calculate the amplitude of the signal pulse expected from a NaI(Tl)-PM tube combination under the following circumstances:

- Radiation energy loss: 1.2 MeV
- Light collection efficiency: 70%
- Photocathode efficiency: 20%
- PM electron gain: 100 000
- Anode capacitance: 100 pF

As a signal pulse consider the pulse amplitude (voltage) induced due to the anode capacitance.

Additional material

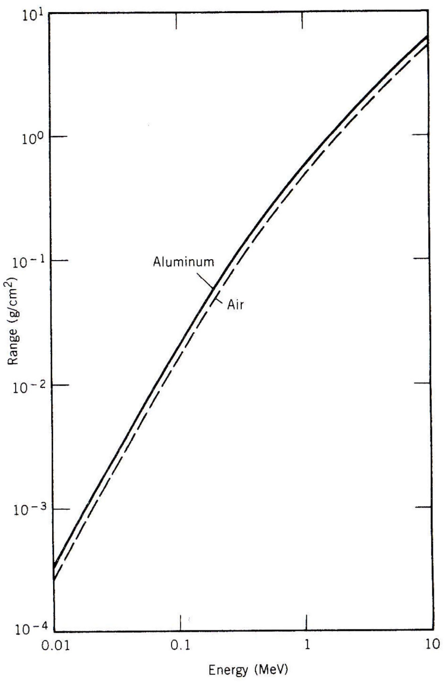

Figure 7.4 Range-energy relationship for electrons in air and in aluminum.

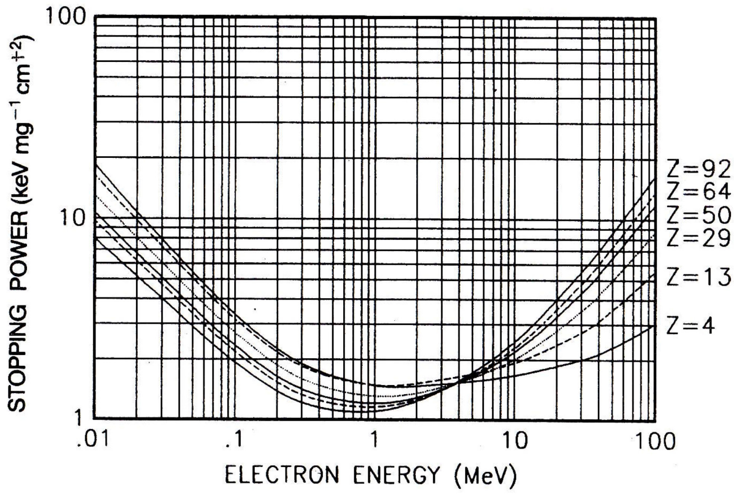

Figure 7-10 Stopping power of electrons in the energy range from 0.01 MeV to 100 MeV for a number of elements. For low-Z substances, dE/dx is almost constant between about 0.5 MeV and several MeV. The rise of the curves at high energies is due to increasing bremsstrahlung probability.

Relevant properties of intrinsic Si and Ge

	Si	Ge
atomic number	14	32
density (g/cm^3)	2.33	5.32
atomic density (atoms/cm^3)	4.96×10^{22}	4.41×10^{22}
dielectric constant (relative to vacuum)	12	16
band gap (eV) 300 K	1.115	0.665
0 K	1.165	0.746
intrinsic carrier density at 300 K (/cm^3)	1.5×10^{10}	2.4×10^{13}
mobility (cm^2/V/s) at 300 K: electrons	1350	3900
holes	480	1900
mobility (cm^2/V/s) at 77 K: electrons	2.1×10^4	3.6×10^4
holes	1.1×10^4	4.2×10^4
ionisation energy (eV) 300 K	3.62	(*)
77 K	3.76	2.96

Table 8.3 Properties of Common Inorganic Scintillators

	Specific Gravity	Wavelength of Max. Emission	Refractive Index	Decay Time (μs)	Abs. Light Yield in Photons/MeV	Relative Pulse Height Using Bialk. PM tube	References
Alkali Halides							
NaI(Tl)	3.67	415	1.85	0.23	38 000	1.00	
CsI(Tl)	4.51	540	1.80	0.68 (64%), 3.34 (36%)	65 000	0.49	78, 90, 91
CsI(Na)	4.51	420	1.84	0.46, 4.18	39 000	1.10	92
Li(Eu)	4.08	470	1.96	1.4	11 000	0.23	
Other Slow Inorganics							
BGO	7.13	480	2.15	0.30	8200	0.13	
$CdWO_4$	7.90	470	2.3	1.1 (40%), 14.5 (60%)	15 000	0.4	98–100
ZnS(Ag) (polycrystalline)	4.09	450	2.36	0.2		1.3[a]	
CaF_2 (Eu)	3.19	435	1.47	0.9	24 000	0.5	
Unactivated Fast Inorganics							
BaF_2 (fast component)	4.89	220		0.0006	1400	na	107–109
BaF_2 (slow component)	4.89	310	1.56	0.63	9500	0.2	107–109
CsI (fast component)	4.51	305		0.002 (35%), 0.02 (65%)	2000	0.05	113–115
CsI (slow component)	4.51	450	1.80	multiple, up to several μs	varies	varies	114, 115
CeF_3	6.16	310, 340	1.68	0.005, 0.027	4400	0.04 to 0.05	76, 116, 117
Cerium-Activated Fast Inorganics							
GSO	6.71	440	1.85	0.056 (90%), 0.4 (10%)	9000	0.2	119–121
YAP	5.37	370	1.95	0.027	18 000	0.45	78, 125
YAG	4.56	550	1.82	0.088 (72%), 0.302 (28%)	17 000	0.5	78, 127
LSO	7.4	420	1.82	0.047	25 000	0.75	130, 131
LuAP	8.4	365	1.94	0.017	17 000	0.3	134, 136, 138
Glass Scintillators							
Ce activated Li glass[b]	2.64	400	1.59	0.05 to 0.1	3500	0.09	77, 145
Tb activated glass[b]	3.03	550	1.5	~3000 to 5000	~50 000	na	145
For comparison, a typical organic (plastic) scintillator:							
NE102A	1.03	423	1.58	0.002	10 000	0.25	

[a]for alpha particles

[b]Properties vary with exact formulation. Also see Table 15.1.

The grading scheme

- written idea on how to solve the problem: 20%
- 80% of the grade is equally shared by steps required by the problem. Number of steps depends on the method chosen by student to solve the problem. If there is a mistake in derivation during the step, grade for this step is reduced by 20%.