Chemistry 985

Fall, 2o11 Exam # 1 **OPEN BOOK**
Distributed: Tues., 18 Oct. 11, 8:30AM Due: 18 Oct. 11, 10:00AM

1. (10 points) A recent seminar speaker mentioned during his talk at the NSCL that a goal for the purity of germanium material needed for neutrino-less beta decay was 1 μBq/kg of germanium (Z=32, Molar Mass=72.64 g/mol). If you assume that the major impurity is ^{40}K ($T_{1/2}$=1.251Gy, β^- emitter) what is the desired atomic ratio of ^{40}K to Ge in this material?

2. Provide concise written answers to the following five questions about the very popular XP2202 photomultiplier tubes based on a variety of the information in the attached spec-sheet from Photonis.

   (a) (10 points) What is the value of the quantum efficiency of this tube?

   (b) (10 points) What is the average value of δ for the dynodes in this tube when operated with voltage divider scheme **B** that is called the "best compromise"?

   (c) (10 points) Explain the basis for the statement: "Other things being equal, the lime-glass window in this tube is better suited to plastic scintillators than NaI(Tl) or BGO."

   (d) (10 points) Explain the basis for the statement: "This tube would be a poor choice for a BaF_2 scintillator."

   (e) (10 points) What is the maximum signal height in volts created by a pulse of 1000 photoelectrons when this tube is operated in a AC coupled mode (divider scheme B, 250 pF output capacitor) into a circuit with a 50 Ω impedance?

3. The so-called Neutral Current Detectors in the Sudbury Neutrino Observatory (SNO) were gas-filled proportional counters. These devices were cylindrical, 5.0 cm diameter and 200 cm long, filled with either a mixture of ^{3}He/CF_4 or ^{4}He/CF_4 at 2.50 atm in the ratio 85:15 giving w=39eV. They had a 50μm diameter anode wire operated at 1950 V

connected to a 93 Ω cable and circuit. The SNO group measured the Diethorn parameters for this gas to be ΔV=34. V and K=1.77x10^4 V/cm-atm and a multiplication factor of 220. See NIM A579(2007)1054 for details. The expression for the capacitance of a cylindrical detector of length L, should you need it, is C=$\pi\epsilon_o L/ln(r_{cathode}/r_{anode})$.

(a) (10 points) What is the maximum pulse height in volts of the signal generated by a neutron capture in the ^{3}He filled detectors if the event leaves the maximum energy of 0.764 MeV in the detector gas?

(b) (5 points) Show that the reported gain value is consistent with the other reported parameters.

(c) (5 points) Describe the process of Penning ionization and would you expect it to be present in these detectors?

4. (10 points) Consider a 1 MeV photon that interacts in a standard 3"x3" NaI(Tl) crystal by undergoing two successive Compton scattering events that are separated by 3.00 cm and then exits the crystal. Calculate the ratio of the time between the two scattering events to the mean lifetime of the scintillation light produced by this detector.

5. (10 points, 2 each) Provide **concise** and accurate answers to the following five questions about vacuum equipment.

(a) Describe the operating principle of a Pirani vacuum gauge.

(b) Why do cold-cathode gauges require a magnetic field to operate?

(c) Give the common meaning of Q in the equation Q=PS and can Q have the dimensions of Joule/s?

(d) Under what gas-load conditions would a turbomolecular pump with a given speed and a low compression ratio be preferable to a similar pump with the same speed and a high compression ratio?

(e) What is a virtual leak in a vacuum system?

A standard, 10-stage, 51mm (2") tube

Applications :	For scintillation counting, laboratory and industrial photometry.		
Description :	Window :	Material : Photocathode : Refr. index at 400 nm :	lime glass bi-alkali 1.54
	Multiplier :	Structure : Nb of stages :	linear focused 10
	Mass :	110 g	

Photocathode characteristics

	Spectral range :					290-650	nm
		Maximum sensitivity at :				400	nm
	Sensitivity ① :						
		Luminous :			typ.:	70	µA/lm
☑		Blue :	min.:	9	typ.:	10	µA/lmF
		Radiant, at 400 nm :			typ.:	75	mA/W

Characteristics with voltage divider A

	Gain slope (vs supp. volt., log/log) :					7.5	
	For an anode blue sensitivity of :					10	A/lmF
☑	Supply voltage :		max.: min.:	1500 1100	typ.:	1250	V
	Gain :					10^6	
☑	Anode dark current ② :		max:	20	typ.:	3	nA
	Pulse height resolution ^{137}Cs ③ :				typ.:	7.2	%
	Pulse height resolution ^{55}Fe ④ :				typ.:	42	%
	Mean anode sensitivity deviation ⑤ :						
		long term (16 h) :				1	%
		after change of count rate :				1	%
		vs temperature between 0 and +40 °C at 420 nm :				- 0.2	%/K
	Gain halved for a magnetic field of :						
		perpendicular to axis "n" :				0.2	mT
		parallel to axis "n" :				0.1	mT

Characteristics with voltage divider ⑦ :

		B	A	
For a supply voltage of :		1700	1700	V
Gain :		1.8×10^6	7.5×10^6	
Linearity (2%) of anode current up to :		200	100	mA
Anode pulse ⑦ :	Rise time :	4	4	ns
	Duration at half height :	8	8	ns
	Transit Time :	36	35	ns
Capacitance	anode to all :	5		pF

Recommended voltage divider

Type A for maximum gain

K	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	A	
2	1	1	1	1	1	1	1	1	1	1		(total :12)

Type B for best timing / linearity compromise

K	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	A	
2	1	1	1	1.25	1.25	1.5	2.25	2.25	2.5	2.25		(total :18.25)

K: photocathode Dn: dynode A: anode

Limiting values

Anode luminous sensitivity :				max.:	75	A/lmF
Supply voltage :				max.:	1800	V
Continuous anode current :				max.:	0.2	mA
Voltage between :	D1 and photocathode :	min.:	150	max.:	600	V
	consecutive dynodes :			max.:	300	V
	anode and D10 :	min.:	30	max.:	300	V
Ambient temperature :	short operation (< 30 mn) :	min.:	-30	max.:	+80	°C
	continuous operation & storage :	min.:	-30	max.:	+50	

Notes

☑ Characteristic measured and mentioned on the test ticket of each tube.

① Luminous sensitivity is measured with a tungsten filament lamp with a colour temperature of 2856 ± 5 K. The blue sensitivity, expressed in A/lmF ("F" as in Filtered) is measured with a tungsten filament lamp with a colour temperature of 2856 ±. 5 K. Light is transmitted through an interference filter.

② Dark current is measured at ambient temperature, after the tube has been in darkness for approximately 1 min. Lower value can be obtained after a longer stabilisation period in darkness (approx. 30 min.).

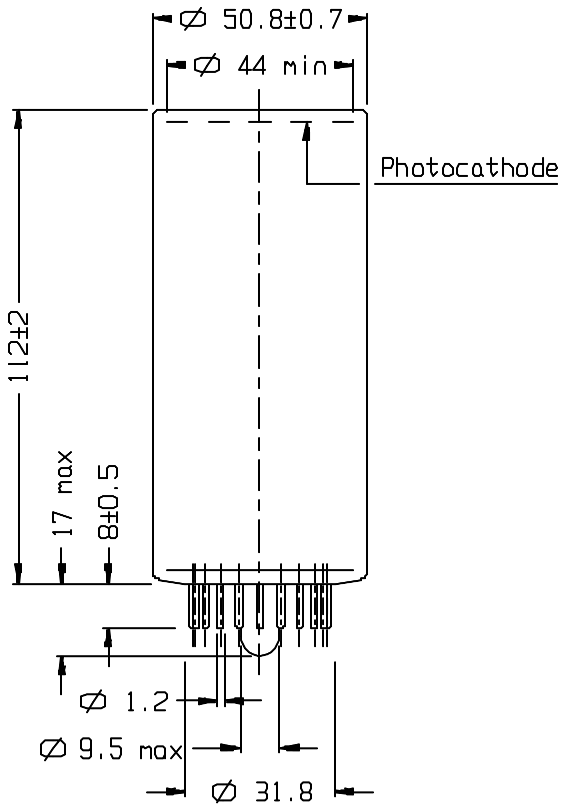
③ Pulse amplitude resolution for ^{137}Cs and ^{57}Co is measured with NaI(Tl) cylindrical scintillator with a diameter of 32 mm and a height of 25 mm. The count rate used is ~ 1.0 x 10^4 c/s.

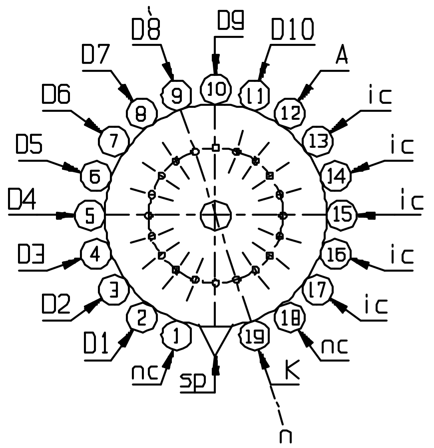
④ Pulse amplitude resolution for ^{55}Fe is measured by coupling a NaI(Tl) cylindrical scintillator with a diameter of 32 mm and a height of 1 mm provided with a beryllium window. The count rate used is ~ 1.0 x 10^4 c/s.

⑤ The mean pulse amplitude deviation is measured by coupling a NaI(Tl) scintillator to the window of the tube. Long term (16h) deviation is measured by placing a ^{137}Cs source at a distance from the scintillator such that the count rate is ~1.E+04 c/s, corresponding to an anode current of ~ 300 nA. The mean pulse amplitude deviation after change of count rate is measured with a ^{137}Cs source at a distance from the scintillator such that the count rate can be changed from 1.E+04 to 1.E+03 c/s, corresponding to an anode current of ~1 µA and 0.1 µA respectively. Both tests are carried out according to ANSI-N42-9-1972 of IEEE recommendations.

⑥ To obtain a peak pulse current greater than that obtainable with divider A, it is necessary to increase the inter-dynode voltage progressively. Divider circuit C is an example of a progressive divider, giving a compromise between gain, speed and linearity. other dividers can be conceived to achieve other compromises. It is generally recommended that the voltage ratio between two successive stages is less than 2.

⑦Measured with a pulse light source, with a pulse duration (FWHM) of approximately 1ns., the cathode being completely illuminated. The rise time is determined between 10 % and 90 % of the anode pulse amplitude. The signal transit time is measured between the instant at which the illuminating pulse of the cathode becomes maximum, and the instant at which the anode pulse reaches its maximum. Rise time, pulse duration and transit time vary with respect to high tension supply voltage Vht as (Vht)-½.

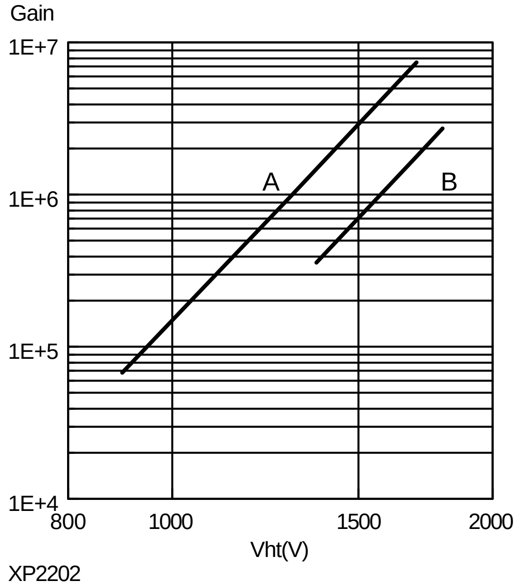




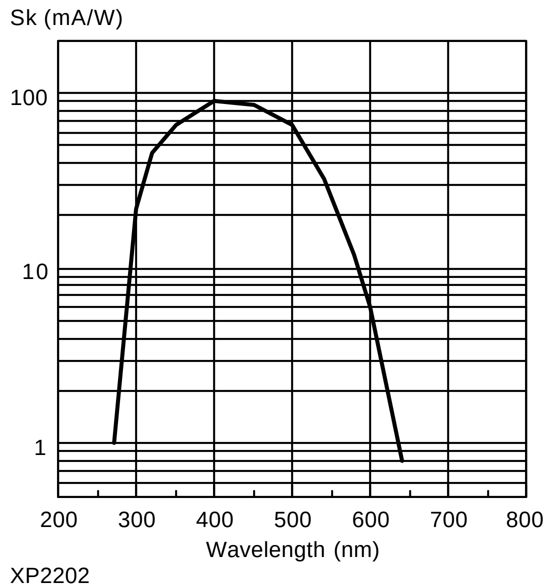
ref.: 87500018
sp: short pin
nc: not connected
Ic: internal connection
n: plane of symmetry of the multiplier

K: cathode Dn: dynode
A: anode

Typical gain curve



Typical spectral characteristics



Accessories

Socket:	FE2019
Mu-metal shield:	MS152