

A Digital Method for Measurement of Gamma-Ray Attenuation Coefficient

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A digital method for the measurement of total attenuation coefficient of materials for gamma rays is described. The method is suitable when the thickness of the absorber involved is small. The system described is all digital and the display indicates directly the value of the total attenuation coefficient.

1. Introduction

THE PRESENT DAY methods for the measurement of total attenuation coefficient of materials for gamma rays are similar to the one used in the original experimental work of Davisson and Evans¹. They are all basically analogue in nature. They are also time-consuming and involve some manual computation for the actual calculation of the total attenuation coefficient. It is, however, preferable to have an instrument which directly gives the value of the attenuation coefficient in digits. In this paper, a complete digital system for such a purpose is described. The digital display indicates the value of the attenuation coefficient directly. No analogue operations are involved. The instrument has been tested with 0.66 MeV ¹³⁷Cs gamma rays and with aluminium and lead absorbers of various thicknesses.

2. Outline of the Method

The usual expression for the attenuation coefficient is given by :

$$N = N_0 e^{-\mu x} \quad \dots(1)$$

where N_0 = counts registered without the absorber, N = counts registered with the absorber, μ = the total attenuation coefficient, and x = the thickness of the absorber. Expanding the exponential, we have

$$N = N_0 \left(1 - \mu x + \frac{\mu^2 x^2}{2!} - \frac{\mu^3 x^3}{3!} + \dots \right) \quad \dots(2)$$

Assuming μx to be small and calling $\Delta = \frac{N_0 - N}{N_0}$, we get

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$$\mu = \frac{\Delta}{x} \quad \dots(3)$$

By fixing N_0 and x , μ is obtained directly. On the basis of the above principle, a system is designed to display the value of μ directly.

For this scheme of operation, three digital counters A, B and C are essential. The counters A, B and C are of the same capacity (10,000 in our set-up). A and B can operate only in the 'UP' mode whereas C can work both in the 'UP' and 'DOWN' modes². To start with, a fixed number of gamma pulses say $N_0 = 10,000$ is stored in A. The time taken to register these counts, say T sec, is registered in C by making it work in the 'UP' mode. Next, the absorber is placed between the source and the detector and the pulses are registered in B; during the operation, C is made to work in the 'DOWN' mode. Counts N are now registered in B till the contents of C becomes zero, i. e. B is allowed to function for the same time duration T . The contents of B ($=N$) are then subtracted from that of A ($=N_0$) by digital subtraction techniques and the output is stored in a decade scaler. It is evident from Eq. (1) that the contents ($N_0 - N$) of this decade scaler will directly give the value of μ (except for the decimal place), provided that the thickness of the absorber is say 1 cm. Even if the thickness is 0.1 cm, only the decimal point in μ has to be shifted. Thus, it is possible to obtain the value of the total attenuation coefficient in cm^{-1} (or in any other unit such as g/cm^2).

3. Electronic Set-up

Fig. 1 shows the schematic block diagram of the measuring system which includes the logic functions

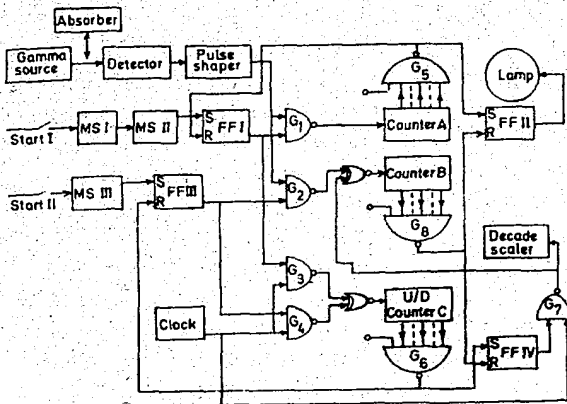


Fig. 1 - Block diagram of the experimental set-up

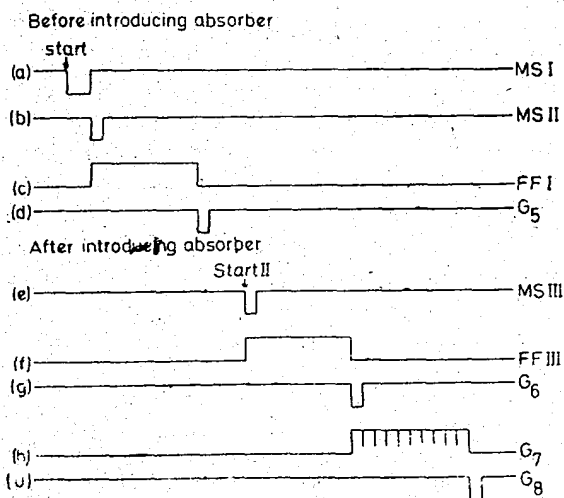


Fig. 2 - Timing diagram for the experimental set-up shown in Fig. 1

for 'Start I' and 'Start II' operations. The operations can be easily explained with reference to the timing diagram shown in Fig. 2.

The gamma-ray source is kept at a 'suitable' distance from the detector and the pulses are fed to counters A and B through a pulse-shaper. No absorber is as yet placed between the source and the detector. When 'Start I' switch is closed, the monostable MS-I is triggered. During the '1' to '0' transition of MS-I, all the flip-flops are 'reset' and the counters A, B and C are cleared of their contents. After a delay of about one μ sec, MS-I comes back to its original stage. This '0' to '1' transition is made use of to trigger the monostable MS-II [Fig. 2 (a)]. During the '1' to '0' transition of MS-II, the flip-flop FF-I is 'set'. This enables the 'NAND' gates G_1 and G_2 and also sets C to operate in the 'UP' mode. Gamma-ray pulses pass into the counter A through G_1 . C starts counting the clock pulses in the forward

direction, i.e. in the 'UP' mode. This operation continues till the value of the counts registered in A reaches a pre-determined value N_0 ($=10,000$ in our case). When the value N_0 is reached, the output of the 'NAND' gate G_5 goes from '1' to '0' [Fig. 2 (d)] and this transition is used to reset FF-I and also to 'set' FF-II. This means that G_1 and G_2 will inhibit further passage of gamma pulses and clock pulses to A and C respectively. FF-II drives a lamp 'ON' indicating that the storing of 10,000 counts in A is complete.

Now the absorber of suitable thickness, say 1 cm of aluminium, is introduced between the gamma-ray source and the detector. The 'Start II' switch is now closed. This triggers monostable MS-III and at the '1' to '0' transition of its output the flip-flop FF-III is 'set' [Fig. 2 (f)]. This enables the 'NAND' gates G_2 and G_4 and also 'sets' C to operate in the 'DOWN' mode. Gamma pulses are now stored in B through G_2 and C starts counting the clock pulses in the reverse direction (i.e. in the 'DOWN' mode) through G_4 . This operation continues until the contents of C are reduced to zero. At this stage the output of the 'NAND' gate G_6 goes from '1' to '0' [Fig. 2 (g)] and this transition resets FF-III [Fig. 2 (f)]. This means that G_2 and G_4 inhibit the gamma pulses and the clock pulses respectively. Let the number of counts registered in B be N .

The output of G_6 also 'sets' the flip-flop FF-IV. This enables the clock pulses from an astable multivibrator, (indicated as a clock in Fig. 1) of frequency 1 kHz (which is adjustable) pass to B and also to the decade scaler (model DS 327 A manufactured by M/s Electronics Corp. of India Limited, Hyderabad) through the 'NAND' gate G_7 . This initiates the digital subtraction process and the operation continues until B reads 10,000 at which instant the output of the 'NAND' gate G_8 goes from '1' to '0' which transition is used to reset FF-IV and FF-II. Thus, the number stored in the decade scaler gives the value of $(N_0 - N)$. This number, displayed with the help of nixie tubes, directly gives μ the total attenuation coefficient when the decimal point is properly introduced.

It may be pointed out that one of the digital counters, either A or B, may be removed from the circuit because both are not counting simultaneously. The counts N_0 and N can both be stored in the same digital counter. Depending on the counting rate of gamma pulses, the frequency of the clock pulses from a voltage-controlled oscillator may be adjusted so as to have a reasonable number of counts stored in C. Thus for a given gamma-ray source one particular frequency can be selected.

Table 1—Values of Total Attenuation Coefficient (μ)

Thickness (cm)	μ (cm^{-1})	
	Without Correction	With correction
(A) With aluminium absorber		
1	0.1087	0.1152
2	0.1030	0.1153
3	0.0970	0.1148
4	0.0930	0.1149
5	0.0875	0.1152
6	0.0838	0.1146
(B) With lead absorber		
0.2	0.915	0.010
0.4	0.834	1.009
0.6	0.760	1.014
0.8	0.695	1.015
1.0	0.638	1.016
1.2	0.587	1.015

4. Experimental Results and Conclusions

The instrument has been tested using the ^{137}Cs 0.66 MeV gamma-ray source. Aluminium and lead absorbers of various thicknesses have been used. The results obtained are given in Table 1. The numbers displayed on the nixie tubes, along with the appropriate decimal point and after dividing by the absorber thickness, are indicated in column 2. As the thickness of the absorber is increased, the numbers in column 2 deviate more from the true result. This is due to the fact that μ cannot be calculated accurately from Eq. (3) when μx is not much smaller than 1. However, even for thick absorbers, the actual value of μ can be obtained by applying the correction indicated below to the numbers displayed on the nixie tubes. Eq. (1) may be easily rewritten in terms of Δ as

$$\mu = - (2.303/x) \log_{10} (1 - \Delta) \quad \dots(4)$$

The values obtained using Eq. (4) are given in column 3 of Table 1. For small absorber thicknesses of Al and Pb, the values in column 3 differ from those in column 2 by only about 5 to 10%. All the numbers in column 3 agree to within about 1% which is of the same order of magnitude as the statistical errors involved in the experiment.

It may be pointed out that our values of μ , quoted in column 3 of Table 1, differ slightly from the values quoted by Davission and Evans¹ because our experiment was done in open geometry without any collimation except for the fact that a 0.4 cm lead plate was used to cover the detector before starting the experiment. A good geometry arrangement capable of giving accurate values of μ has recently been described by Gopal and Sanjeevaiah². In conclusion, it may be stated that our method is particularly suitable if $\mu x \ll 1$ and in such a case, the numbers displayed on the nixie tubes directly give the value of the gamma-ray attenuation coefficient. If thicker absorbers are used, a correction can be easily applied.

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