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Silicon Photon Cross Section Using Logarithmic Scale

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Abstract- A logarithmic scale is a nonlinear scale used when there is a large range of quantities. Common uses include the earthquake strength, sound loudness, light intensity, and pH of solutions. It is based on orders of magnitude, rather than a standard linear scale, so each mark on the scale is the previous mark multiplied by a value. If both the vertical and horizontal axes of a plot are scaled logarithmically, the plot is referred to as a Log/Log plot.

In [4] we learned about the Cartesian scale graphs and study the silicon photon absorption (Si photon) cross section. Before reading this paper you may want to review that research. In this study we will learn how to plot quantities on a new type of graph called a logarithmic graph. We will see how this can make it easier to determine the functional relationship between certain quantities. We will motivate logarithmic graphs using silicon photon absorber data.

In this study we choose the silicon element to study the Log/Log (scattering coherent, scattering incoherent, photon electric absorption, total attenuation with coherent, total attenuation without coherent and mass energy absorption). The photon absorber data, pair production in nuclear field (cm^2/g) and pair production in electron field (cm^2/g) for silicon photon are also discussed.

Keywords- *Scattering, Coherent, Incoherent, Photon electric absorption, Total attenuation with coherent, Total attenuation without coherent, Mass energy absorption*

I. INTRODUCTION

In science and engineering, a log–log graph or log–log plot is a two-dimensional graph of numerical data that uses logarithmic scales on both the horizontal and vertical axes. Monomials – relationships of the form $y = ax^k$ appear as straight lines in a log–log graph, with the power and constant term corresponding to slope and intercept of the line, and thus these graphs are very useful for recognizing these relationships and estimating parameters. Any base can be used for the logarithm, though most common are 10, e, and 2 [1-3]. Two types of logarithmic graphs are useful:

1. The semi-log graph, which has a logarithmic vertical scale and a linear horizontal scale, as shown below.
2. The log-log graph, which has a logarithmic vertical scale and a logarithmic horizontal scale, as shown below.

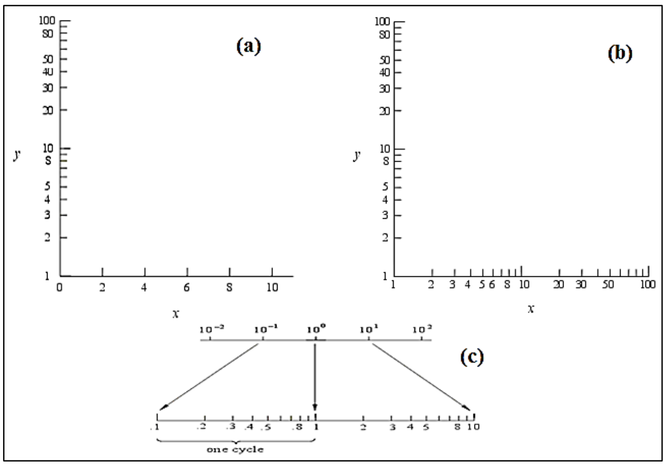

Figure 1. (a) The semi-log graph, (b) log-log graph and (c) the logarithmic scale of the kind used on logarithmic graph paper.

Figures 1shows a logarithmic scale of the kind used on logarithmic graph paper. It is not a linear scale because larger numbers are allotted less space than smaller numbers. The lower part of figure 1 (part (c)) shows the logarithmic scale in more detail. The numbers along the axis are located where their logarithms would be placed on linear graph paper. This means that we can plot *x* itself on logarithmic graph paper rather than plot log (*x*) on linear graph paper. Notice that moving to the left along a logarithmic axis only makes the numbers smaller and smaller. Zero is located an infinite distance to the left and negative numbers do not exist. The range from one power of 10 to the next is called a cycle.

1. A straight line on a semilog graph of *y* versus *x* represents an exponential function of the form: $y = a\,e^{bx}$.
2. A straight line on a log-log graph of *y* versus *x* represents a power law function of the form: $y = a\,x^{b}$.

To find the constants *a* and *b*, we can substitute two widely-spaced points which lie on the line into the appropriate equation. This gives two equations for the two unknowns *a* and *b* which can be solved by elimination.

II. THEORY

In physics, absorption of electromagnetic radiation is the way in which the energy of a photon is taken up by matter, typically the electrons of an atom. Thus, the electromagnetic energy is transformed into internal energy of the absorber, for example thermal energy. The reduction in intensity of a light wave propagating through a medium by absorption of a part of its photons is often called attenuation. Usually, the absorption of waves does not depend on their intensity (linear absorption), although in certain conditions (usually, in optics), the medium changes its transparency dependently on the intensity of waves going through, and saturable absorption (or nonlinear absorption) occurs.

The cross section is an effective area that quantifies the intrinsic likelihood of a scattering event when an incident beam strikes a target object, made of discrete particles. In a completely classical setting, where a particle is nothing more than a hard object, the cross section is the area of the conventional geometric cross section, and expresses the probability of hitting the object with a ray. It is typically denoted σ and measured in units of area. In scattering experiments, one is often interested in knowing how likely a given event is to occur. However, the rate depends strongly on experimental variables such as the density of the target material, the intensity of the beam, or the area of overlap between the beam and the target material. To control for these mundane differences, one can factor out these variables, resulting in an area-like quantity known as the cross section.

Cross section is associated with a particular event (e.g. elastic collision, a specific chemical reaction, a specific nuclear reaction) involving a certain combination of beam (e.g. light, elementary particles, nuclei) and target material (e.g. colloids, gases, atoms, nuclei). Often there are additional factors that can affect the cross section in complicated ways, such as the energy of the beam. For a given event, the cross section σ is given by [4]:

$$\sigma = \frac{\mu}{n} \tag{1}$$

where, σ is the cross section of this event (SI units: m^2), μ is the attenuation coefficient due to the occurrence of this event (SI units: m^{-1}), and n is the number density of the target particles (SI units: m^{-3}).

Equivalently, if the target material is a thin slab placed perpendicular to the beam, one may express the cross section in terms of flux:

$$\sigma = \frac{1}{n\Phi} \left(-\frac{d\Phi}{dz}\right) \tag{2}$$

Where, - $d\Phi$ is the amount of flux lost due to the occurrence of this event, dz is the thickness of the target material, and Φ is the flux of the incident beam.

For a target of finite area, the cross section is given by:

$$\sigma = \frac{1}{n\mathrm{IA}} \frac{d\mathrm{W}}{dz} \tag{3}$$

Where, $d\mathrm{W}/\mathrm{dz}$ is the rate at which the event occurs per distance traversed (SI units: m^{-1} s^{-1}), I is the particle flux (or intensity) of the incident beam (SI units: m^{-2} s^{-1}), and A is the area of overlap between the beam and the target (SI units: m^2).

Schematically, an event is said to have a cross section of σ if its rate is equal to that of collisions in an idealized classical experiment where:

1. The beam is replaced by a stream of inert point-like particles.
2. The target particles are replaced by inert and impenetrable disks of area σ (and hence the name "cross section"), with all other experimental variables kept the same as the original experiment.

If a beam enters a thin layer of material of thickness dz, the flux of the beam Φ will decrease according to:

$$\frac{d\Phi}{dz} = -n\sigma\Phi \tag{4}$$

Where, σ is the total cross section of all events, including scattering, or to absorption, or transformation to another species. Solving this equation leads to the exponentially decaying behavior:

$$\Phi = \Phi_0 e^{-n\sigma z} \tag{5}$$

Where, Φ_0 is the initial flux. For light, this is called the Beer–Lambert law. This basic concept can then extended to the cases where the interaction probability in the targeted area assumes intermediate values, because the target itself is not homogeneous, or because the interaction is mediated by a non-uniform field [4].

For light, as in other settings, the scattering cross section is generally different from the geometrical cross section of a particle, and it depends upon the wavelength of light and the permittivity, shape and size of the particle. The total amount of scattering in a sparse medium is proportional to the product of the scattering cross section and the number of particles present.

In terms of area, the total cross section (σ) is the sum of the cross sections due to absorption, scattering and luminescence:

$$\sigma = \sigma_a + \sigma_s + \sigma_l \tag{6}$$

The total cross section is related to the absorbance of the light intensity through the Beer–Lambert law, which says absorbance is proportional to concentration:

$$A_\lambda = C\ell\sigma \tag{7}$$

Where, A_λ is the absorbance at a given wavelength λ, C is the concentration as a number density, and ℓ is the path length. The absorbance of the radiation is the logarithm (decadic or, more usually, natural) of the reciprocal of the transmittance [4]:

$$A_\lambda = -log \tag{8}$$

III. SIMULATION RESULTS AND DISCUSSION

In this section, we study the results of:

1. The photon absorber data, pair production in nuclear field and pair production in electron field for Si.
2. Log/Log Scattering – Coherent.
3. Log/Log Scattering – Incoherent.
4. Log/Log Photon Electric Absorption.

5. Log/Log Total Attenuation with Coherent.
6. Log/Log Total Attenuation without Coherent.
7. Log/Log Mass Energy Absorption.

The photon absorber data, pair production in nuclear field (cm^2/g) and pair production in electron field (cm^2/g) for Si are listed in Table 1.

TABLE I. THE PHOTON ABSORBER DATA FOR SI TABLETED.

No.	Photon Energy (MeV)	Pair Production in Nuclear Field (cm^2/g)	Pair Production in Electron Field (cm^2/g)	No.	Photon Energy (MeV)	Pair Production in Nuclear Field (cm^2/g)	Pair Production in Electron Field (cm^2/g)
1	0.001	0	0	42	12	0.01011	0.000437
2	0.0015	0	0	43	13	0.01064	0.000477
3	0.001839	0	0	44	14	0.01114	0.000514
4	0.001839	0	0	45	15	0.0116	0.00055
5	0.002	0	0	46	16	0.01204	0.000584
6	0.003	0	0	47	18	0.01284	0.000648
7	0.004	0	0	48	20	0.01355	0.000705
8	0.005	0	0	49	22	0.01419	0.000759
9	0.006	0	0	50	24	0.01478	0.000808
10	0.008	0	0	51	26	0.01532	0.000854
11	0.01	0	0	52	28	0.01581	0.000896
12	0.015	0	0	53	30	0.01627	0.000936
13	0.02	0	0	54	40	0.01817	0.001102
14	0.03	0	0	55	50	0.01958	0.001231
15	0.04	0	0	56	60	0.0207	0.001334
16	0.05	0	0	57	80	0.02236	0.001493
17	0.06	0	0	58	100	0.02354	0.001611
18	0.08	0	0	59	150	0.02547	0.00181
19	0.1	0	0	60	200	0.02663	0.001939
20	0.15	0	0	61	300	0.02802	0.002102
21	0.2	0	0	62	400	0.02884	0.002202
22	0.3	0	0	63	500	0.02938	0.002273
23	0.4	0	0	64	600	0.02976	0.002326
24	0.5	0	0	65	800	0.0303	0.002399
25	0.6	0	0	66	1000	0.03064	0.002449
26	0.8	0	0	67	1500	0.03113	0.002524
27	1	0	0	68	2000	0.03139	0.002567
28	1.022	0	0	69	3000	0.03169	0.002614
29	1.25	3.52E-05	0	70	4000	0.03186	0.002642
30	1.5	0.000191	0	71	5000	0.03195	0.002659
31	2	0.000753	0	72	6000	0.03203	0.002672
32	2.044	0.000812	0	73	8000	0.03212	0.002687
33	3	0.002139	1.21E-05	74	10000	0.03218	0.002697
34	4	0.003456	4.95E-05	75	15000	0.03225	0.002712
35	5	0.004629	9.85E-05	76	20000	0.03229	0.002719
36	6	0.005678	0.000151	77	30000	0.03236	0.002727
37	7	0.006611	0.000204	78	40000	0.03238	0.002734
38	8	0.007451	0.000255	79	50000	0.03238	0.002736
39	9	0.008212	0.000304	80	60000	0.0324	0.002738
40	10	0.008905	0.000351	81	80000	0.0324	0.00274
41	11	0.009531	0.000395	82	100000	0.03242	0.002742

The results of Log/Log graph, which has a logarithmic vertical scale and a logarithmic horizontal scale, as shown below:

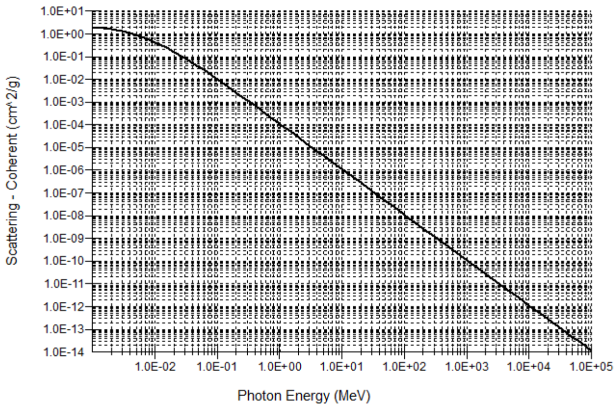

Figure 2. The relationship between Log/Log (scattering – coherent and photon energy).

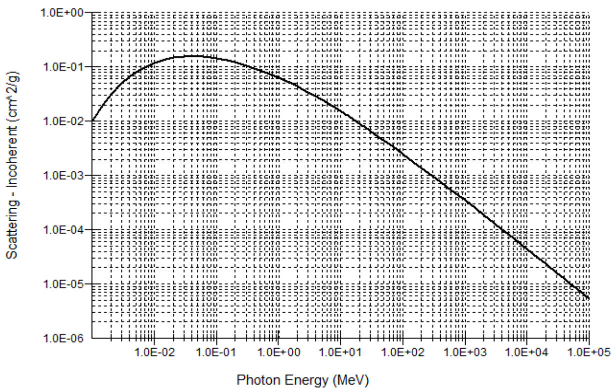

Figure 3. The relationship between Log/Log (scattering – incoherent and photon energy).

Figure 2 and 3 shows the relationship between Log/Log (photon energy with scattering-coherent and scattering-incoherent) respectively. The coherent scattering varies with the atomic number of absorber (Z) and incident photon energy (E) by Z^2 / E. Coherent scattering is important for low kilo voltage photons, and increases with increasing atomic number.

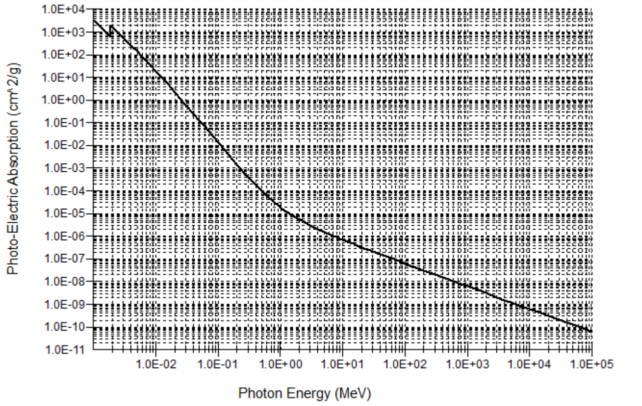

Figure 4. Log/Log photon electric absorption of Si versus photon energy.

Figure 4 shows the relationship between the Log/Log (photon electric absorption and the photon energy). In the atomic photo effect, a photon disappears and an electron is ejected from an atom. The electron carries away all of the energy of the absorbed photon, minus the energy binding the electron to the atom. The K-shell electrons are the most tightly bound, and are the most important contributions to the atomic photo effect cross-section in most cases. However, if the photon energy drops below the binding energy of a given shell, an electron from that shell cannot be ejected. Hence, particularly for medium- and high-Z elements, a plot of photon electric absorption versus the photon energy exhibits the characteristic saw tooth absorption edges, since the binding energy of each electron subshell is attained and this process is permitted to occur.

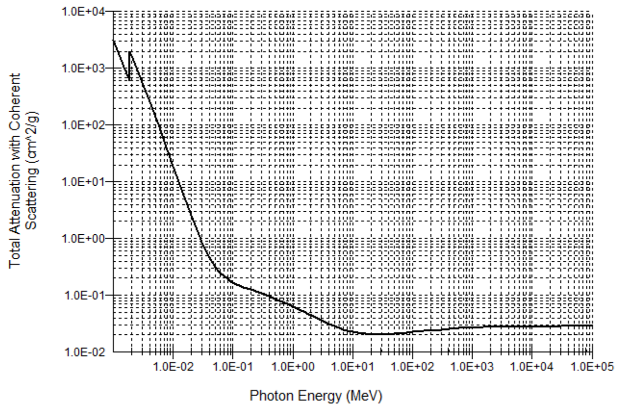

Figure 5. Relationship between Log/Log (total attenuation with coherent and photon energy).

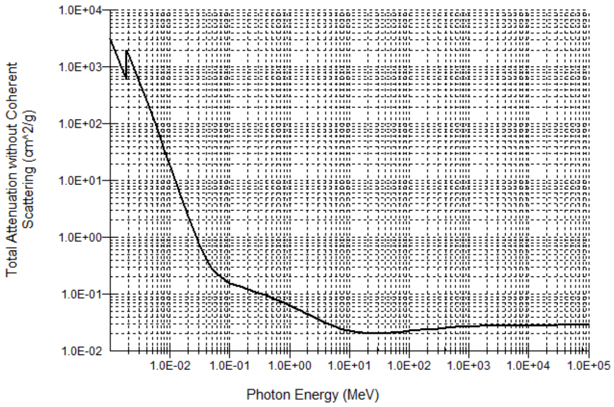

Figure 6. Relationship between Log/Log (total attenuation without coherent and photon energy).

Figure 5 and 6 show the relationship between Log/Log (photon energy and the total attenuation with and without coherent) respectively. Attenuation is the progressive loss of energy by a beam as it traverses matter. A photon beam may be attenuated by any of the processes described in the previous section. There are some more useful concepts when considering the attenuation of photon beams.

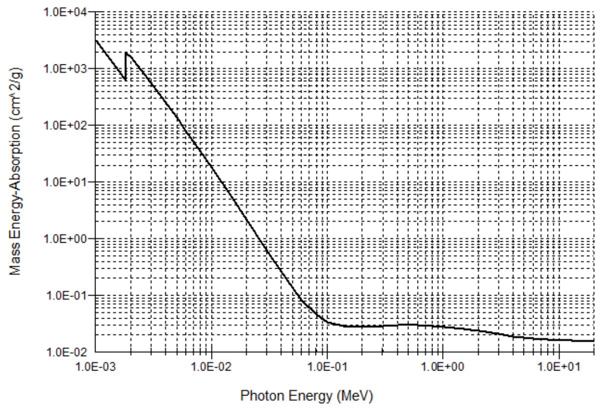

Figure 7. Relationship between Log/Log (mass energy absorption and photon energy).

Figure 7 show the relationship between Log/Log (mass energy absorption and photon energy). The mass incoherent scattering attenuation coefficient is similar for most values of Z, but decreases slowly with increasing beam energy. It is most dependent on the electron density.

IV. CONCLUSIONS

1. One purpose of logarithmic graph is simply to put wide ranges of data on one graph.
2. Another purpose of logarithmic graph is to quickly check if a function follows an exponential law or a power law.
3. The cross section was decreases with increasing the silicon energy and the values compatible in the theoretical calculations.
4. Changing the attenuation values, means change all of the thickness and the photon energy, where the linear and mass attenuation commensurate with the increase in thickness and photon energy. So, the mass attenuation coefficient has a similar behavior to the coefficient of linear attenuation, i.e., proportionality between them.
5. The atomic cross section area of materials mentioned above decreases with an increase in the photon energy, where the atomic cross section values depend on the electronic area section.
6. Pair production often refers specifically to a photon creating an electron-positron pair near a nucleus but can more generally refer to any neutral boson creating a particle-antiparticle pair and the exact analytic form for the cross section of pair production must be calculated through quantum electrodynamics in the form of Feynman diagrams and results in a complicated function.

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