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Study the Radiation Shielding Material of Iron Oxides on the basis of Total Cross Section

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Abstract: *The goal of this work is to investigate the total cross section of electrons, atoms, and molecules in iron oxides. On the basis of this total cross section, one can choose the best radiation shielding material of iron oxides in a radiation field ranging from 0MeV to 10MeV. At low energy, the total cross section of electrons, atoms, and molecules is large, indicating that scattering is significant. High scattering indicates photon divergence and material protection behind the target, implying radiation shielding. As a result, the best radiation shielding material is iron rich oxides with a high FW of iron. Electrons have a smaller total cross section than atoms and molecules. The total cross section of electrons, atoms, and molecules is the same as that of a high energy photon.*

Key Word*: Total cross section, Photon, Radiation shielding material, Iron Oxides*

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I. Introduction

The mass attenuation coefficients (MAC) of an Ag/Cu/Zn alloy with 14.80 percent /57.61 percent /27.59 percent weight fraction determined with gamma rays in the energy range 220 to 662 keV are in good agreement with theoretical values, with an error of less than 1%. Because photons interact strongly with Ag/Cu/Zn alloy, MAC decreases as gamma ray energies increase [1]. Shielding material for photons, such as gamma and X-rays, has atomic number with thinness, whereas shielding material for neutrons has lower hydrogen with thicker. Beta particles can penetrate human skin with a few millimeters and be completely shielded by a material of 5-10 millimeters. Betas shielding materials are effective against bremsstrahlung.

The linear attenuation coefficient (LAC) measures the dependence of the absorption coefficient on the density of the absorbing material. The relationship between electron density (ρ_e) and bulk density of a material (ρ_m) is constant because the Z/A ratio is almost constant and related as $\rho_e = Z\frac{\rho_m}{A}$. The ratio of LAC to density is denoted as MAC(μ), with the unit cm^2/g. Gamma-ray shielding materials are dense and have a high atomic number. As a result, such materials have a high total LAC and a high probability of photoelectric absorption. In today's world, lead is a highly shielding material with a suitable density of $11.35 g/cm^3$, a high atomic number, and a low cost. The total MAC of elements and compounds such as Cr, Co, Fe, $CrCl_2$, $CrCl_3$, $Cr_2(SO_4)_3K_2SO_4{\cdot}24H_2O$, CoO, $CoCl_2$, $Co(CH_3COO)_2$, $FePO_4$, $FeCl_3{\cdot}6H_2O$, $Fe(SO_4)2NH_4{\cdot}12H_2O$ was measured at different energies ranging from 4.508 to 14.142 keV, indicating that they are used as secondary excitation[2].

The mass energy absorption coefficient (MEAC) and kerma relative to air were calculated using iron and chromium alloys and iron nickel alloys with 182 eV at 5.9 keV. This is due to the fact that photoelectric cross sections are affected by atomic numbers [3]. Photon absorption occurs when a photon disappears or converts its total energy to matter. Scattering of photons occurs when photons change direction. The change in direction consumes less energy and causes less damage to the material behind the target. Building infrastructure is made up of concrete, which contains water, cement, aggregate, and other materials, and is widely used, resulting in radiation. As a result, it is necessary to protect the material and organism from rationing, and knowing the attenuation coefficient is the best way to select the low and radiation-protective material. The best radiation shielding materials are those with a

high atomic number and density. The materials we use in our daily lives are composites of several materials, and the best shield material for X-ray and gamma photon interactions can be chosen. The thickness of the shielding material should be satisfy $2 \leq ln\left(\frac{I_0}{I}\right) \leq 4$ with transmission $0.5 \geq T \geq 0.25$. Here I_0 is incident intensity and I is transmitted intensity of X-ray beam. The MAC of composed materials containing various elements, according to the mixture rule, is the sum of the fraction weight (FW) of each individual atom and the product of corresponding atoms MAC, expressed as,

$$\left(\frac{\mu}{\rho}\right)_{comp} = \sum w_i \left(\frac{\mu}{\rho}\right)_i \tag{1}$$

The photon attenuation coefficients are affected by photon energy and material density, which is critical for radiation shielding [4]. Here $w_i, (\mu_m)_i$ are weight fraction and MAC of i[th] element and material composed of multi elements is expressed as,

$$w_i = \frac{n_i A_i}{\sum_i n_i A_i} \tag{2}$$

Here A_i, n_i are atomic weight of the i[th] element and number of formula units. The total molecular cross-section (σ_t^m) for materials can be expressed as

$$(\sigma_t^m) = \frac{1}{N_A} \sum_i \left(\frac{\mu}{\rho}\right)_i n_i A_i \tag{3}$$

The total atomic cross-section (σ_t^a) for the element is expressed [5, 6] as

$$(\sigma_t^a) = \frac{(\sigma_t^m)}{\sum_i n_i} \tag{4}$$

The total electronic cross-section (σ_t^e) for the element is expressed as

$$(\sigma_t^e) = \frac{1}{N_A} \sum_i f_i \frac{A_i}{Z_i} \left(\frac{\mu}{\rho}\right)_i, \quad f_i = \left(\frac{n_i}{\sum_i n_i}\right) \tag{5}$$

Here f_i, Z_i are fractional abundance of the element i[th] and atomic number atoms, the effective atomic number of the compounds are represented [7] as $Z_{eff} = \frac{\sigma_t^a}{\sigma_t^e}$.

II. Material And Methods

If a beam of monochromatic photons of passes with incidence energy (E_0), photon flux (Φ_0) through homogeneous material of thickness x then the emergent flux (Φ) according to Beer–Lambert law is given as $\Phi = \Phi_0 e^{-\mu x}$. Here, $\mu\,(cm^{-1})$ is the linear attenuation coefficient. Moreover, the flux is also represent as $\Phi = \Phi_0 e^{-\left(\frac{\mu}{\rho}\right)\rho x}$ from Beer-Lambert law. Here, $\frac{\mu}{\rho}\ (cm^2 g^{-1})$ is the mass attenuation coefficient and LAC is given as

$$\mu = \frac{\rho \sigma_t^e(E) Z N_A}{A} \ or\ \mu = \sigma_t^e(E)\left(\frac{\rho Z N_A}{A}\right) \tag{6}$$

Here, N_A is the Avogadro's number, Z is the atomic number and A is the material atomic mass. The electron density, linear attenuation coefficient and σ_t^e is related as $\mu = \sigma_t^e(E)\delta_e$.

Klien-Nishina Differential Cross Section with Atomic Number

Compton scattering dominates for 511 Kev photons because the incident photon collides with an atomic electron, resulting in atomic ionization. The incident photon will scatter at an angle determined by the KIein-Nishina atomic differential cross section equation, which is as follows:

$$\left(\frac{d\sigma}{d\Omega}\right)_a = \frac{Zr_e^2}{2}\left(\frac{1}{1+\alpha(1-cos\theta)}\right)^2 \left((1+\cos^2\theta) + \frac{\alpha^2(1-cos\theta)^2}{[1+\alpha(1-cos\theta)]}\right) \tag{7}$$

On integrating equation (7) the total atomic cross section per atom is obtained as

$$\sigma_t^a = 2\pi \int_0^\pi \left(\frac{d\sigma}{d\Omega}\right)_a sin\theta d\theta \tag{8}$$

Now substituting from equation (7) in (8), we get:

$$\sigma_t^a = 2\pi \int_0^\pi \frac{Zr_e^2}{2}\left(\frac{1}{1+\alpha(1-cos\theta)}\right)^2 \left((1+\cos^2\theta) + \frac{\alpha^2(1-cos\theta)^2}{[1+\alpha(1-cos\theta)]}\right) sin\theta d\theta \tag{9}$$

On solving the total KN cross section per atom is obtained as,

$$\sigma_t^a = Z2\pi r_0^2 \left\{ \frac{1+\alpha}{\alpha^2} \left[\frac{2(1+\alpha)}{1+2\alpha} - \frac{\ln(1+2\alpha)}{\alpha} \right] + \frac{\ln(1+2\alpha)}{2\alpha} - \frac{1+3\alpha}{(1+2\alpha)^2} \right\} \quad (10)$$

Since we have $\sigma_a = Z\,\sigma_e$, therefore from equation (9), the total electronic cross section for KN is

$$\sigma_t^e = 2\pi r_0^2 \left\{ \frac{1+\alpha}{\alpha^2} \left[\frac{2(1+\alpha)}{1+2\alpha} - \frac{\ln(1+2\alpha)}{\alpha} \right] + \frac{\ln(1+2\alpha)}{2\alpha} - \frac{1+3\alpha}{(1+2\alpha)^2} \right\} \quad (11)$$

Here, $r_0 = 2.818 \times 10^{-13} m$ is the classical electron radius, Z is the nuclear charge of the target molecule and $\alpha = \frac{E}{m_e c^2} = \frac{hf}{0.511 MeV}$ [8-9]. On putting the value of σ_e in $\frac{\mu}{\rho} = \frac{\sigma_e Z N_A}{A}$ we get,

$$\frac{\mu}{\rho} = 2C\left(\frac{ZN_A}{A}\right) \quad (12)$$

Here, $C = \pi r_0^2 \left\{ \frac{1+\alpha}{\alpha^2} \left[\frac{2(1+\alpha)}{1+2\alpha} - \frac{\ln(1+2\alpha)}{\alpha} \right] + \frac{\ln(1+2\alpha)}{2\alpha} - \frac{1+3\alpha}{(1+2\alpha)^2} \right\}$. Therefore, this equation gives mass attenuation coefficient in term of KN parameters and known as Compton mass attenuation coefficient is calculated using, $\frac{\mu}{\rho} = N_A Z \frac{\sigma_e}{A}$. Where N_A is the Avogadro's number ($6.02 \times 10^{23}\ atom/mol$), Z is the atomic number and A is the material atomic mass [10].

Total molecular Cross Section of iron oxides

Now total molecular cross section (TMC) of FeO from equation (1) and (3) and (12) for fraction weight (FW) 0.5, 0.2 and 0.8,

$$(\sigma_t^m)_{FeO} = C[Z_{Fe} + Z_O],\ FW\ Fe = 0.5, O = 0.5 \quad (13a)$$
$$(\sigma_t^m)_{FeO} = C[1.6Z_{Fe} + 0.2Z_O]\ FW\ Fe = 0.8, O = 0.2 \quad (13b)$$
$$(\sigma_t^m)_{FeO} = C\ [0.2Z_{Fe} + 1.6Z_O]\ FW\ Fe = 0.2, O = 0.8 \quad (13c)$$

The Iron(II) oxide or ferrous oxide with chemical formula FeO and also called wüstite. The melting and boiling point of FeO is 1,377°C and 3,414°C respectively with density 5.61g/cm^3. The equation (13) gives the TMC of FeO with FW of iron and Oxygen. The crystal is monoclinic with band energy is 2.303eV and space group C2/m. The TMC of Fe_2O_3 from equation (1) and (3) and (12) for fraction weight (FW) 0.5, 0.2 and 0.8,

$$(\sigma_t^m)_{Fe_2O_3} = C[2Z_{Fe} + 3Z_O], FW\ Fe = 0.5, O = 0.5 \quad (14a)$$
$$(\sigma_t^m)_{Fe_2O_3} = C[3.2Z_{Fe} + 0.6Z_O], FW\ Fe = 0.8, O = 0.2 \quad (14b)$$
$$(\sigma_t^m)_{Fe_2O_3} = C[0.8Z_{Fe} + 4.8Z_O], FW\ Fe = 0.2, O = 0.8 \quad (14c)$$

The Iron (III) oxide or ferric oxide with chemical formula Fe_2O_3 and also called rust. The melting and boiling point of Fe_2O_3 is 1,597°C and 2,623°C respectively with density 5.07g/cm^3. The equation (14) gives the TMC of Fe_2O_3 with FW of iron and Oxygen. The crystal is trigonal with space group R$\bar{3}$c. The TMC of Fe_3O_4 from equation (1) and (3) and (12) for FW 0.5, 0.2 and 0.8,

$$(\sigma_t^m)_{Fe_3O_4} = C[3Z_{Fe} + 4Z_O], \quad FW\ Fe = 0.5, O = 0.5 \quad (15a)$$
$$(\sigma_t^m)_{Fe_3O_4} = C[4.8Z_{Fe} + 1.6Z_O], FW\ Fe = 0.8, O = 0.2 \quad (15b)$$
$$(\sigma_t^m)_{Fe_3O_4} = C[1.2Z_{Fe} + 6.4Z_O]\ , FW\ Fe = 0.2, O = 0.8 \quad (15c)$$

The Iron(II,III) oxide with chemical formula Fe_3O_4 and also called magnetite. The melting and boiling point of Fe_3O_4 is 1,597°C and 2,623°C respectively with density 5.61g/cm^3. The equation (15) gives the TMC of Fe_3O_4 with FW of iron and Oxygen. The crystal is cubic with space group FD$\bar{3}$m. The TMC of Fe_7O_8 from equation (1) and (3) and (12) for fraction weight (FW) 0.5, 0.2 and 0.8,

$$(\sigma_t^m)_{Fe_7O_8} = C[7Z_{Fe} + 8Z_O],\ FW\ Fe = 0.5, O = 0.5 \quad (16a)$$
$$(\sigma_t^m)_{Fe_7O_8} = C[11.2Z_{Fe} + 3.2Z_O], FW\ Fe = 0.8, O = 0.2 \quad (16b)$$
$$(\sigma_t^m)_{Fe_7O_8} = C[2.8Z_{Fe} + 12.8Z_O], FW\ Fe = 0.2, O = 0.8 \quad (16c)$$

The Fe_7O_8 is triclinic crystal and density is 5.19g/cm^3 with band energy 1.065eV and space group P$\bar{1}$. The equation (16) gives the TMC of Fe_7O_8 with FW of iron and Oxygen. The TMC of Fe_8O_9 from equation (1) and (3) and (12) for fraction weight (FW) 0.5, 0.2 and 0.8,

$$(\sigma_t^m)_{Fe_8O_9} = C[8Z_{Fe} + 9Z_O], FW\ Fe = 0.5, O = 0.5 \quad (17a)$$
$$(\sigma_t^m)_{Fe_8O_9} = C[12.2Z_{Fe} + 3.6Z_O], FW\ Fe = 0.8, O = 0.2 \quad (17b)$$
$$(\sigma_t^m)_{Fe_8O_9} = C[3.2Z_{Fe} + 14.4Z_O], FW\ Fe = 0.2, O = 0.8 \quad (17c)$$

The Fe_8O_9 is triclinic crystal and density is 5.30g/cm^3 with band energy 1.198eV and space group P1. The equation (17) gives the TMC of Fe_8O_9 with FW of iron and Oxygen. The TMC of Fe_9O_{10} from equation (1) and (3) and (12) for fraction weight (FW) 0.5, 0.2 and 0.8,

$$(\sigma_t^m)_{Fe_9O_{10}} = C[9Z_{Fe} + 10Z_O], FW\ Fe = 0.5, O = 0.5 \quad (18a)$$
$$(\sigma_t^m)_{Fe_9O_{10}} = C[14.4Z_{Fe} + 4Z_O], FW\ Fe = 0.8, O = 0.2 \quad (18b)$$
$$(\sigma_t^m)_{Fe_9O_{10}} = C[3.6Z_{Fe} + 16Z_O], FW\ Fe = 0.2, O = 0.8 \quad (18c)$$

The Fe_9O_{10} is triclinic crystal and density is 5.35g/cm^3 with band energy 1.604eV and space group P$\bar{1}$. The equation (18) gives the TMC of Fe_9O_{10} with FW of iron and Oxygen. The TMC of $Fe_{10}O_{11}$ from equation (1) and (3) and (12) for fraction weight (FW) 0.5, 0.2 and 0.8,

$$(\sigma_t^m)_{Fe_{10}O_{11}} = C[10Z_{Fe} + 11Z_O], FW\ Fe = 0.5, O = 0.5 \quad (19a)$$
$$(\sigma_t^m)_{Fe_{10}O_{11}} = C[16Z_{Fe} + 4.4Z_O], FW\ Fe = 0.8, O = 0.2 \quad (19b)$$
$$(\sigma_t^m)_{Fe_{10}O_{11}} = C[4Z_{Fe} + 17.6Z_O], FW\ Fe = 0.2, O = 0.8 \quad (19c)$$

The $Fe_{10}O_{11}$ is triclinic crystal and density is 5.36g/cm^3 with band energy 1.425eV and space group P$\bar{1}$. The equation (19) gives the TMC of $Fe_{10}O_{11}$ with FW of iron and Oxygen. The TMC of $Fe_{11}O_{12}$ from equation (1) and (3) and (12) for fraction weight (FW) 0.5, 0.2 and 0.8,

$$(\sigma_t^m)_{Fe_{11}O_{12}} = C[11Z_{Fe} + 12Z_O], FW\ Fe = 0.5, O = 0.5 \quad (20a)$$
$$(\sigma_t^m)_{Fe_{11}O_{12}} = C[17.6Z_{Fe} + 4.8Z_O], FW\ Fe = 0.8, O = 0.2 \quad (20b)$$
$$(\sigma_t^m)_{Fe_{11}O_{12}} = C[4.4Z_{Fe} + 19.2Z_O], FW\ Fe = 0.2, O = 0.8 \quad (20c)$$

The $Fe_{11}O_{12}$ is triclinic crystal and density is 5.38g/cm^3 with band energy 1.392eV and space group P$\bar{1}$. The equation (20) gives the TMC of $Fe_{11}O_{12}$ with FW of iron and Oxygen. The TMC of $Fe_{14}O_{15}$ from equation (1) and (3) and (12) for fraction weight (FW) 0.5, 0.2 and 0.8,

$$(\sigma_t^m)_{Fe_{14}O_{15}} = C[14Z_{Fe} + 15Z_O], FW\ Fe = 0.5, O = 0.5 \quad (21a)$$
$$(\sigma_t^m)_{Fe_{14}O_{15}} = C[22.4Z_{Fe} + 6Z_O], FW\ Fe = 0.8, O = 0.2 \quad (21b)$$
$$(\sigma_t^m)_{Fe_{14}O_{15}} = C[5.6Z_{Fe} + 24Z_O], FW\ Fe = 0.2, O = 0.8 \quad (21c)$$

The $Fe_{14}O_{15}$ is tetragonal crystal and density is 5.54g/cm^3 with band energy 1.020eV and space group I4/m. The equation (21) gives the TMC of $Fe_{14}O_{15}$ with FW of iron and Oxygen. The TMC of $Fe_{17}O_{18}$ from equation (1) and (3) and (12) for fraction weight (FW) 0.5, 0.2 and 0.8,

$$(\sigma_t^m)_{Fe_{17}O_{18}} = C[17Z_{Fe} + 18Z_O], FW\ Fe = 0.5, O = 0.5 \quad (22a)$$
$$(\sigma_t^m)_{Fe_{17}O_{18}} = C[27.2Z_{Fe} + 7.2Z_O], FW\ Fe = 0.8, O = 0.2 \quad (22b)$$
$$(\sigma_t^m)_{Fe_{17}O_{18}} = C[6.8Z_{Fe} + 28.8Z_O], FW\ Fe = 0.2, O = 0.3 \quad (22c)$$

The $Fe_{17}O_{18}$ is triclinic crystal and density is 5.44g/cm^3 with band energy 1.519eV and space group P$\bar{1}$. The equation (22) gives the TMC of $Fe_{17}O_{18}$ with FW of iron and Oxygen. The TMC of $Fe_{23}O_{25}$ from equation (1) and (3) and (12) for fraction weight (FW) 0.5, 0.2 and 0.8,

$$(\sigma_t^m)_{Fe_{23}O_{25}} = C[23Z_{Fe} + 25Z_O], FW\ Fe = 0.5, O = 0.5 \quad (23a)$$
$$(\sigma_t^m)_{Fe_{23}O_{25}} = C[36.8Z_{Fe} + 10Z_O], FW\ Fe = 0.8, O = 0.2 \quad (23b)$$
$$(\sigma_t^m)_{Fe_{23}O_{25}} = C[9.2Z_{Fe} + 40Z_O], FW\ Fe = 0.2, O = 0.8 \quad (23c)$$

The $Fe_{23}O_{25}$ is triclinic crystal and density is 5.42g/cm^3 with band energy 1.388eV and space group P$\bar{1}$. The equation (23) gives the TMC of $Fe_{23}O_{25}$ with FW of iron and Oxygen. The TMC of $Fe_{32}O_{35}$ from equation (1) and (3) and (12) for fraction weight (FW) 0.5, 0.2 and 0.8,

$$(\sigma_t^m)_{Fe_{32}O_{35}} = C[32Z_{Fe} + 35Z_O], FW\ Fe = 0.5, O = 0.5 \quad (24a)$$
$$(\sigma_t^m)_{Fe_{32}O_{35}} = C[51.2Z_{Fe} + 14Z_O], FW\ Fe = 0.8, O = 0.2 \quad (24b)$$
$$(\sigma_t^m)_{Fe_{32}O_{35}} = C[12.8Z_{Fe} + 56Z_O], FW\ Fe = 0.2, O = 0.8 \quad (24c)$$

The $Fe_{32}O_{35}$ is triclinic crystal and density is 5.32g/cm^3 with band energy 0.508eV and space group P1. The equation (24) gives the TMC of $Fe_{32}O_{35}$ with FW of iron and oxygen.

III. Results and Discussion

Total Atomic Cross Section (TACS) of Iron and Oxygen

Figure 1 depicts the TACS of an iron and an oxygen atom. The representation shows that the TACS of the iron atom is greater than that of the oxygen atom. The TACS for both atoms is of the order of 10(-23) m2, and the TACS provides information about radiation scattering when photons incident on or hit these atoms. Because scattering is one of the most important topics in nuclear physics, we can learn more about the target without actually making physical contact. In this paper, we investigate the iron oxide cross section (molecular) for radiation shielding in various fields of radiation with energies ranging from 1 to 10 MeV. TACS is high at low energy, decreases with increasing photon energy, and becomes almost constant at high energy, as shown in Figure 1. This is because the

interaction between photon and target is weaker at low energy and stronger at high energy. The TACS is also depend upon atomic number and incidence energy of photon.

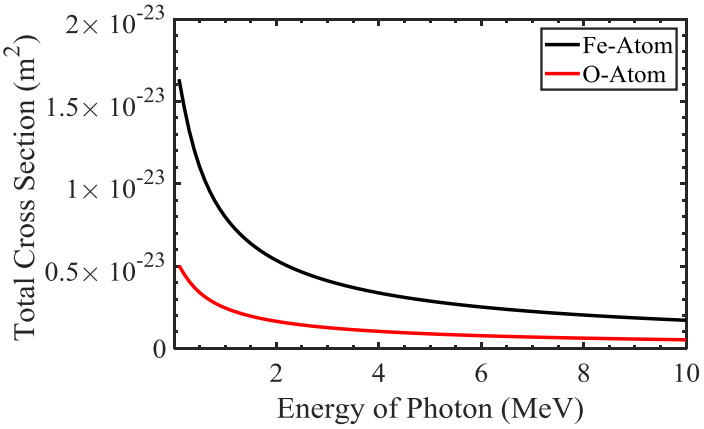


Figure 1: Energy of photon vs total atomic cross section

Total Electronic Cross section (TECS)

The representation of TECS with photon energy is shown in figure 2. The TECS decrease with increasing the photon energy and the order of TECS is of $10^{-25}m^2$ which is lower than TACS by 10^{-2}. TECS is independent on atomic number but depend upon energy of photon.

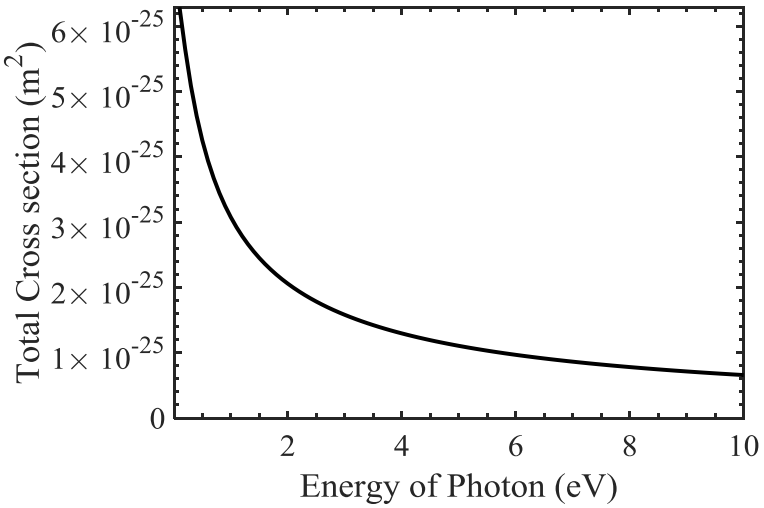
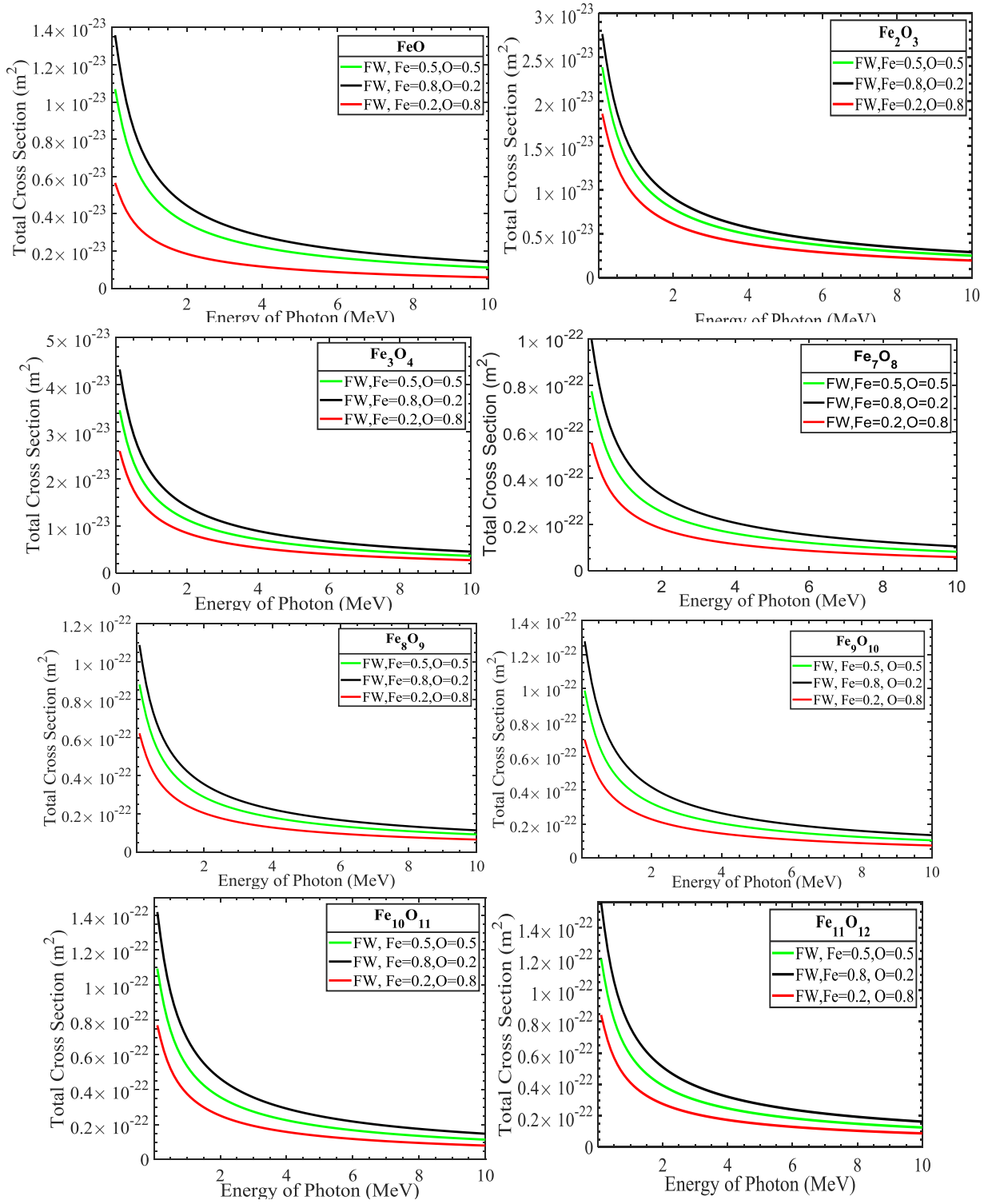


Figure 2: Energy of photon vs total electronic cross section

Total Molecular Cross Section (TMCS) of Iron oxides (molecules)

The TMCS is represented in Figure 3 for possible iron oxides which may be used as radiation shielding. The comparison of TMCS of iron oxides with different FW (50%:50%, 80%:20% and 20%:80%) of Iron and oxygen studies. The TMCS of consider iron oxides ranges from $10^{-23}m^2$ to $10^{-22}m^2$ and TMCS increase as the concentration of oxygen increase (highly oxide iron). The TMCS decrease with increasing the energy of photon and at high energy the TMCS become equal form FW composition. Therefore the small ranges energy is best to study the TMCS of iron oxides because it give detail information about the target. On comparing the TMCS among the consider iron oxides the TMCS of $Fe_{32}O_{35}$ is greater than other iron oxides. The TMCS is less than the TACS and TECS, for more detail one can visualized and compare figure 1, 2, and 3.


FeO
FW, Fe=0.5,O=0.5
FW, Fe=0.8,O=0.2
FW, Fe=0.2,O=0.8
Fe2O3
FW,Fe=0.5,O=0.5
FW,Fe=0.8,O=0.2
FW,Fe=0.2,O=0.8
Fe3O4
FW,Fe=0.5,O=0.5
FW,Fe=0.8,O=0.2
FW,Fe=0.2,O=0.8
Fe7O8
FW,Fe=0.5,O=0.5
FW,Fe=0.8,O=0.2
FW,Fe=0.2,O=0.8
Fe8O9
FW,Fe=0.5,O=0.5
FW,Fe=0.8,O=0.2
FW,Fe=0.2,O=0.8
Fe9O10
FW, Fe=0.5, O=0.5
FW, Fe=0.8, O=0.2
FW, Fe=0.2, O=0.8
Fe10O11
FW, Fe=0.5,O=0.5
FW, Fe=0.8,O=0.2
FW, Fe=0.2,O=0.8
Fe11O12
FW, Fe=0.5,O=0.5
FW,Fe=0.8, O=0.2
FW,Fe=0.2, O=0.8
Total Cross Section (m2)
Energy of Photon (MeV)

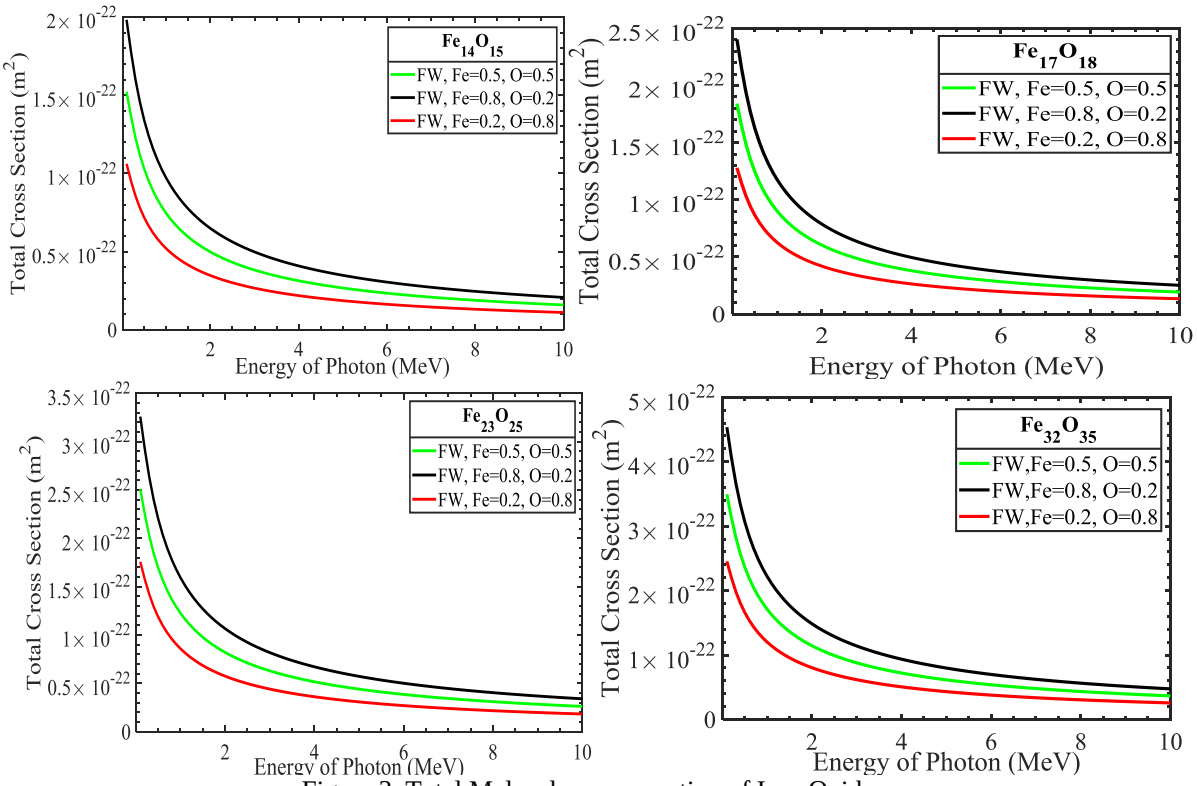


Figure 3: Total Molecular cross section of Iron Oxides

IV. Conclusion

The TMCS, TECS, and TACS are studies for lower to higher order iron oxides that discovered that total cross section (TCS) decreases as photon energy increases. The TCS for low energy photons (0.5MeV) is high, while the TCS for high energy photons (>10MeV) is low. TCS is almost constant and low at very high photon energies. TACS is determined by atomic number and photon energy, whereas TMCS is determined by atomic number, photon energy, and FW, but TECS is determined solely by photon energy. Among the TCS studies, TMCS>TACS>TECS for the same energy of photon and atom. On the basis of these TCS, one can choose the best radiation shielding materials of iron oxides that can be used in various radiation exposure fields.

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