Journal of Chemical Health Risks

www.jchr.org

JCHR (2024) 14(2), 279-284 | ISSN:2251-6727

An Experimental Study on γ-Radiation Attenuation in Tungsten

A.S. Madhusudhan Rao[1], P. Kalyani[2]

[1]Geethanjali College of Engineering and Technology (Autonomous), Hyderabad-501301, Telangana, India

[2]Vignana Bharathi Institute of Technology (Autonomous), Hyderabad-501301, Telangana-India

(Received: 07 January 2024 Revised: 12 February 2024 Accepted: 06 March 2024)

KEYWORDS

Attenuation; Linear Attenuation coefficient, Thermal expansion; Density; Mean Free Path.

ABSTRACT:

An experimental investigation was conducted to determine the γ-photons' attenuation in tungsten. The aim of the investigation is to determine the thermophysical characteristics of a tungsten specimen in the 300–1075K temperature range. Furthermore, photon interaction parameters at various γ-photon energies have been assessed by extending the attenuation investigation.

1. Introduction

Of all the metals, tungsten has the lowest expansion coefficient, outstanding high temperature, mechanical qualities, and great strength. Many high-temperature applications, including arc-welding electrodes and heating elements in high-temperature furnaces, require tungsten and its alloys. Tungsten, tungsten alloys, and tungsten compounds have special qualities that make them irreplaceable in key industrial applications of contemporary technology, including electronics, automotive, aircraft, mining, medicine, and defence. It is crucial to chemical applications, electrical and electronic equipment, and other end uses. Lead shielding can be replaced by tungsten radiation shielding capacity. Tungsten alloy radiation shielding is non-toxic, non-polluting, and more environmentally friendly than lead.

Numerous researchers have used a variety of experimental and non-experimental techniques to examine the various properties of tungsten. Various techniques were employed in the investigation of thermal characteristics, particularly thermal expansion [1–14]. Langmuuir investigated the tungsten's thermal properties [1]. Transient interferometry was used by Miiller and Cezairliyan [2] to measure the thermal expansion of tungsten in the 1500–3600 K range. The sample was heated by sending a pulse of electrical current in less than a second. A Michelson interferometer was used to measure the change in the fringe pattern, and a high-speed photoelectric pyrometer was used to determine the sample temperature. The greatest thermal expansion inaccuracy observed is between 1% and 2% in the 2000–3600K range. Equations [2] were utilised to determine the specimen's linear thermal expansion.

$$\frac{l-l_0}{l_0} = \left(\frac{\lambda}{2l_0}\right)\Delta n \quad \text{fringe shift } (\Delta n) \tag{1}$$

$$\frac{(l-l_0)}{l} = 1.3896 \times 10^{-3} - 8.2797 \times 10^{-7}T + 4.0557 \times 10^{-9}T^2 - 1.2164 \times 10^{-12}T^3 + 1.7034 \times 10^{-16}T^4 \tag{2}$$

λ is the wave length of the radiation l_o is the specimen "length" at 20^{0}C.

Knibbs [3] using an electron bombardment furnace in combination with a specially made extensometer to find the thermal expansion coefficient of tungsten at high temperatures. In order to estimate the linear thermal expansions of metals like tungsten from ambient temperature to the temperature of liquid nitrogen, Nix and Macnair [4] utilised an interferometric dilatometer and compared the results with those determined using Grueneisen theory. The following equations (3-5) have been proposed by Worthing [5], V'Yugov and Gumenyuk [6], and White [7] to estimate the thermal expansion of tungsten.

$$\frac{L-L_0}{L_0} = 4.44 \times 10^{-6}(T-300) + 4.5 \times 10^{-11}(T-300)^2 + 2.20 \times 10^{-13}(T-300)^3 \quad [5]\ (3)$$

$$\frac{(L-L_0)}{L_0} = -6.6 \times 10^{-5} + 3.7 \times 10^{-6}t + 8.7 \times 10^{-10}t^2 \quad [6]\ (4)$$

$$\alpha = 4.35 \times 10^{-6} + 0.30 \times 10^{-9}t + 0.51 \times 10^{-12}t^2 \quad [7]\ (5)$$

The X-ray diffraction method was used by Dubrovinsky and Saxena [8] to report molar volumes and thermal expansion in the 300–3600 K range, Deshpande and Pawar [9] from 24° C to 526° C, and Shah and Straumanis [10] to report lattice parameters, thermal expansion coefficients, and Griineisen parameters of tungsten in the 180–40 K temperature range.

$\alpha = 7.862 \times 10^{-6} + 6.392 \times 10^{-9}\mathrm{T}$ [8] (6)

$\alpha_t = 4.33 \times 10^{-6} + 6.94 \times 10^{-6}(t - 20)$ [9] (7)

Over the temperature range of 20° to 500° C, the coefficient of expansion has a mean value of 4-50 x 10^{-6} [9]. This number is in good agreement with the values provided by Dodge [11] for the range 20°–678° C and Goucher [12] for the range 0°–577° C, which are 4-56 X 10^{-6}.The following equation for the thermal expansion of tungsten was reported by Saxena and Zhang [13].

$$\alpha = 9.386 \times 10^{-6} + 5.51 \times 10^{-9}T \qquad (8)$$

The attenuation parameters, including the mass attenuation coefficient, the linear attenuation coefficient, and the Half value layer, Tenth Value Layer and Mean Free Path of various shielding metals at varying γ-energies, such as tungsten were determined by Mohammad Qadr [14].. The NaI(TI) detector was used to measure the attenuation. In comparison to other materials he reported, tungsten offers the best radiation shielding, The attenuation of γ-radiation [15] at various temperatures has been investigated in the current investigation to ascertain the thermophysical characteristics of tungsten. The approach has benefits over alternative approaches [16–17]. In order to examine the specimen's thermophysical properties throughout the temperature range of 300K-1075K and its physical parameters at varying γ-energies, the mass attenuation coefficient (μ_m) is determined. The photon interaction parameters of various materials have previously been determined using a variety of techniques [18–21]. The author has used the transmission method of tiny collimated beams [21]. It was observed that tungsten has intriguing properties and a role in their composites. There is no research on temperature-dependent γ-ray attenuation on tungsten in the literature. There aren't many energy-dependent attenuation studies in the literature. We decided to conduct the current investigation in response to these discoveries.

2. Experimental Details

Using a hydraulic press set to 2400 psi and 22.5 g of powder, a specimen pellet of tungsten is created. The prepared pellet has a thickness of 1.35 cm. The author goes into great depth about the experimental setup and technique in [17, 22, and 23].

The process described in [21] is used to calculate the mass attenuation coefficient (μ_m) of the molecule utilizing γ–photons from energy sources such as ^{137}Cs (0.66MeV), ^{60}Co (1.173MeV & 1.332MeV), and ^{241}Am (0.0595MeV).

The radiation from the sources listed above is applied to the sample. For ten minutes, the detecting device records the intensities transmitted with the sample (I) and without the sample (I_o) under the photo peaks of the Gaussian distribution [21]. Using γ–photons of ^{137}Cs (0.66MeV), the temperature dependence of thermophysical parameters such as density, linear attenuation coefficient, and thermal expansion of (W) has been studied in accordance with the experimental protocol reported [22]. γ-ray counts are detected and recorded at various temperatures within the range of 300K-1075K, both with and without sample (I).

2.1. Computational Details

Using Equations (1–9) of Section 3 [24], the mass attenuation coefficient and other physical parameters at different photon energy are calculated. The uncertainty in the measured physical parameters depends on uncertainty in the temperature of the furnace, errors in recorded intensities and thickness by using the Eqn. 10 [23]. Equations (1–10) of sections (2, 4) [23] are used to calculate the linear attenuation coefficient, density (ρ), and coefficient of linear expansion (α) as functions of temperature.

3. Results and Discussion

Table 1 shows a comparison between the mass attenuation coefficients (μ_m) of tungsten at different γ-energies determined in the current investigation, the X-Com values [19] and the values obtained using the empirical relation provided in [24]. Based on the uncertainties of peak area evaluation, mass thickness measurements, the experimental system, counting statistics, efficiency errors, etc., the estimated error in the experimental measurements is around 1.26%, as determined by Eqn. 19 [22]. Fig. 1 displays the values of (μ_m) from the current investigation. The chance of absorption decreases as incident energy rises.

In the temperature range of 300K to 1075K, the detail study of temperature dependent attenuation of γ-photons of ^{137}Cs (0.66MeV)in the specimen is summarized in Table 2. The ratio of intensity of photons transmitted without sample and after the sample introduced in their path is illustrated in Figure2 and fitted into a quadratic polynomial.

$$(I_0/I)(T) = 13.09 + (-3.6\times10^{-4})T + (-2.43\times10^{-6})T^2 \qquad (9)$$

For the first time, values of the density and linear attenuation coefficient as a function of temperature in

Journal of Chemical Health Risks
www.jchr.org
JCHR (2024) 14(2), 279-284 | ISSN:2251-6727

the temperature range are given; no comparable data from the literature is available. Linear attenuation coefficient is observed to decline from a value of 188.62 m-1 at 300 K to 169.21 m-1 at 1075 K in Figure 3. An equation of second degree is used to represent the variation.

$$\mu_l(T) = (189.5) + (2.5\times10^{-3})T + (-1.92\times10^{-5})T^2 \quad (10)$$

The specimen density decreases from 19250 kgm-3 at 300 K to 17269.30 kgm-3 at 1075 K (Fig.4), it can be expressed in the form of a quadratic equation

$$\rho(T) = (19325) + (3.175\times10^{-1})T + (-2.02\times10^{-3})T^2 \quad (11)$$

The rise in the equilibrium concentration of thermally produced Schottky faults is responsible for the density drop. Defects may arise from γ-ray irradiation. The coefficient of linear thermal expansion found in this study, within the temperature range, is in good agreement with the findings of other techniques reported in the literature. This demonstrates that the fluctuation in density has not been impacted by γ-ray radiation. The equilibrium concentration of defects in Tungsten does not appear to have been impacted by the (30 mci) strength of the source or the (~5hrs) duration of the irradiation in this work.

The thermal expansion (Δl/l) increases with temperature and is fit into the equation

$$(\Delta L/L)(T) = 0.026 + (3.9\times10^{-3})T + (6.3\times10^{-7})T^2 \quad (12)$$

The variation of coefficient of linear thermal expansion (α) with temperature (Fig.5), can be estimated by the equation below

$$\alpha(T) = 4.1 + (4.22\times10^{-4})T + (9.75\times10^{-8})T^2 \quad (13)$$

The mean value of coefficient of linear thermal expansion is 4.42X10-6 K-1 in the range 300-1075K which matches with mean values of coefficient of linear thermal expansion in different temperature ranges of earlier reports [9, 11- 12, 25].

The mass attenuation coefficients obtained in this study at different γ-energies are used to estimate the physical parameters of tungsten, linear attenuation coefficient, total photon interaction cross-sections, effective atomic number, effective electron number, and photon mean free path. These values are contrasted with those estimated from Table 1's semi-empirical relations and X-Com using (μm). The values are in good agreement. Figures 6 and 7 depict the total cross-section (σt) and photon free path, respectively, as a function of γ-energy. As observed in Fig. 7, the photon mean free path (λ) is found to increase with photon energy. This results from a decrease in the likelihood of photons interacting with the substance as energy increases. and is shown to be independent of photon energy, staying constant. The γ-ray attenuation parameters found for tungsten at various energies are consistent with reports from Muhammad Quadr [14].

Table-1 Photon Interaction Parameters of Tungsten (W) at different γ-Energies

Table-1 Temperature dependence of attenuation, density and thermal expansion of Tungsten (W)

Co 1.332MeV	Co1.173MeV			Cs 0.66MeV			Am 0.0595MeV		
X-Com	Expt.	Empirical	X-Com	Expt.	Empirical	X-Com	Expt.	Empirical	X-Com
5.352	5.79	5.83	5.83	9.798	9.809	9.809	378.7	379.3	379.3
103.03	111.46	112.23	112.23	188.61	188.82	188.82	7290	7301.5	7301.5
16.335	17.673	17.779	17.779	29.91	29.94	29.94	1155.9	1157.7	1157.7
2.2076	2.3882	2.4047	2.4047	4.041	4.059	4.046	156.2	156.45	156.45
74	74	74	74	74	74	74	74	74	74
2.4244	2.4244	2.4244	2.4244	2.4244	2.4244	2.4244	2.4244	2.4244	2.4244
0.9706	0.8972	0.891	0.891	0.5302	0.5296	0.5296	0.0137	0.0137	0.0137

Journal of Chemical Health Risks
www.jchr.org
JCHR (2024) 14(2), 279-284 | ISSN:2251-6727

Energy		
PIP	Expt.	Empirical
μ_m [10^{-3} m^2kg^{-1}]	5.329	5.352
μ_l [m^{-1}]	102.58	103.03
σ_t [10^{-25} barn/atom]	16.266	16.335
σ_e [10^{-26} barn/atom]	2.1981	2.2076
Z_{eff}	74	74
N_{eff} [10^{23} electron/g]	2.4244	2.4244
λ [10^{-2} m]	0.9748	0.9706

Table-2 Temperature dependence of attenuation, density and thermal expansion of Tungsten (W)

T[K]	I_0/I	μ_l [m^{-1}]	ρ [kgm^{-3}]	(Δl/l) 10^{-3}	α [$10^{-6}K^{-1}$]	
					[PW]	[5]
300	12.76	188.61	19250	1.26	4.2	4.44
325	12.71	188.33	19221.59	1.37	4.21	4.44
350	12.66	188.05	19193.17	1.48	4.23	4.44
375	12.61	187.73	19160.52	1.59	4.24	4.45
400	12.55	187.41	19127.87	1.7	4.25	4.45
425	12.49	187.05	19090.92	1.81	4.26	4.45
450	12.43	186.69	19053.98	1.92	4.28	4.45
475	12.37	186.29	19012.7	2.04	4.29	4.46
500	12.3	185.88	18971.42	2.15	4.3	4.46
525	12.22	185.43	18925.75	2.27	4.32	4.47
550	12.15	184.99	18880.09	2.38	4.33	4.47
575	12.07	184.5	18829.98	2.5	4.34	4.47
600	11.99	184.01	18779.87	2.61	4.36	4.48
625	11.9	183.47	18725.27	2.73	4.37	4.48
650	11.82	182.94	18670.67	2.85	4.38	4.49
675	11.73	182.36	18611.52	2.97	4.4	4.49
700	11.63	181.78	18552.36	3.09	4.41	4.5
725	11.54	181.15	18488.61	3.21	4.42	4.5
750	11.44	180.53	18424.85	3.33	4.44	4.51
775	11.34	179.86	18356.43	3.45	4.45	4.52
800	11.23	179.19	18288.01	3.57	4.47	4.52
825	11.13	178.47	18214.87	3.7	4.48	4.53
850	11.02	177.75	18141.72	3.82	4.5	4.54
875	10.91	176.99	18063.79	3.95	4.51	4.55
900	10.79	176.23	17985.87	4.07	4.53	4.55
925	10.68	175.41	17903.09	4.2	4.54	4.56
950	10.56	174.6	17820.32	4.33	4.56	4.57
975	10.44	173.74	17732.64	4.46	4.57	4.58
1000	10.32	172.89	17644.96	4.59	4.59	4.59
1025	10.19	171.98	17552.3	4.72	4.6	4.6
1050	10.07	171.07	17459.64	4.85	4.62	4.61
1075	9.818	169.2	17269.3	4.98	4.63	4.62

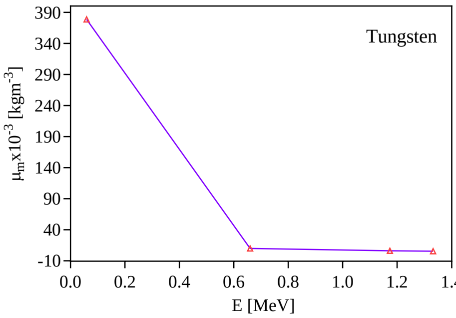

Fig.1. (μ_m) VS Photon Energy

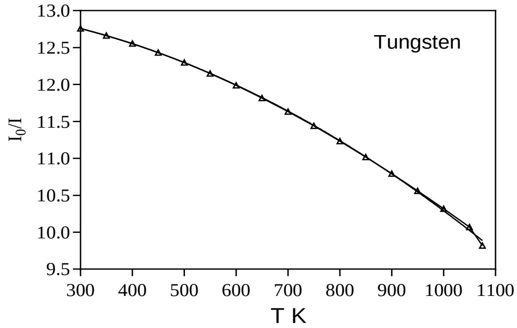

Fig.2. T Vs (I_0/I)

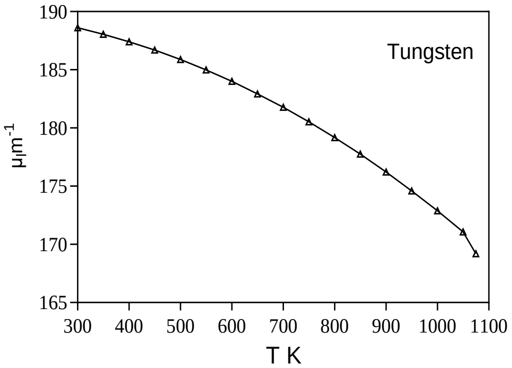

Fig.3. T Vs (μ_l)

Journal of Chemical Health Risks
www.jchr.org
JCHR (2024) 14(2), 279-284 | ISSN:2251-6727

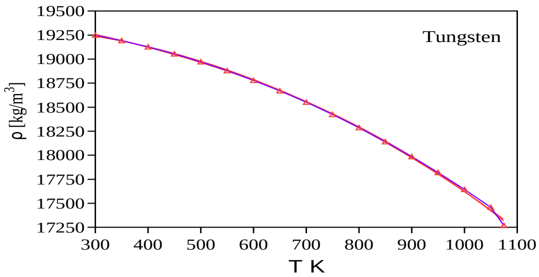

Fig.4. Temperature VS Density (ρ)

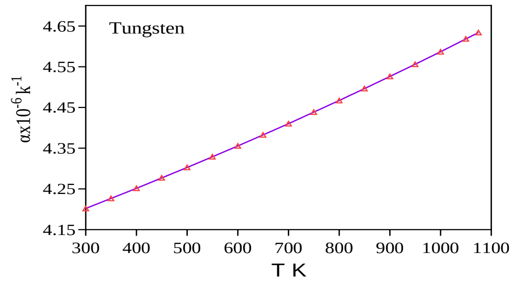

Fig.5. T Vs (α)

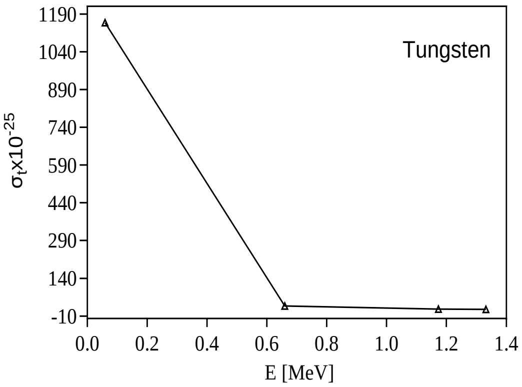

Fig.6. (σ_t) VS Photon energy

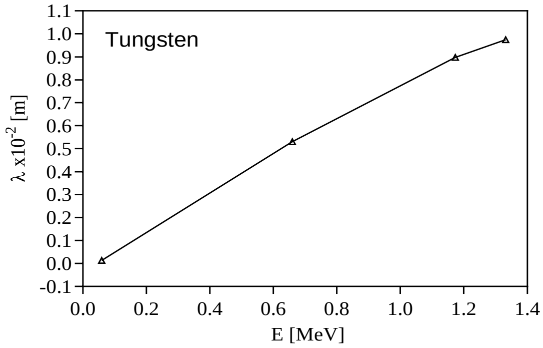

Fig.7. Photon mean free path (λ) VS Photon energy

3. Conclusions

Using 21 grams of powder and a hydraulic press operating at 2310 pounds per square inch, a sample pellet of tungsten is created. The prepared pellet has a thickness of 1.35 cm. A transmission beam method investigation on the attenuation of γ-photons has been carried out experimentally in Tungsten at different energies. For the first time, (μ_m) and additional parameters (σ_t, σ_e, Z_{eff}, N_{eff}, and λ) were estimated at various photon energies. We are aware that the (μ_m) is a sensitive and helpful physical measure that may be used to calculate a specimen's (Z_{eff}) and (N_{eff}). The values of Tungsten (μ_m) drop as photon energy increases. The mass attenuation coefficient and (σ_t and σ_e) vary with energy in the same way. The mass attenuation coefficient, density, linear thermal expansion with temperature, and fluctuation of the linear attenuation coefficient of the tungsten has all been documented. Second order polynomials have been used to depict the temperature dependence of thermal expansion and density, respectively. The coefficient of thermal expansion calculated in this work yields results that are in good agreement with values reported in previous studies published in the literature. This is the first time that the temperature-dependent γ-ray attenuation approach has been applied to Tungsten. This is the first time that the values of and as a function of temperature have been recorded; no comparable data from the literature is available.

References

1. Irving Langmur, The Characteristics of Tungsten Filaments as Functions of Temperature, Phys.Rev.7, p.302, 1916
2. A.P. Miiller and A. Cezairliyan , Thermal Expansion of Tungsten in the Range 1500-3600 K by a Transient Interferometric Technique, International Journal of Thermophysics, Vol. 11, No. 4, 1990, pp. 619-628.
3. R H Knibbs, The measurement of thermal expansion coefficient of tungsten at elevated temperatures, Journal of Scientific Instruments (Journal of Physics E) 1969 Series 2 Volume 2.
4. F. C. Nix and D. Macnair, The Thermal Expansion of Pure Metals. II: Molybdenum, Palladium, Silver, Tantalujm, Tungsten, Platinum, and Lead, Jaxt~Arv 1 and la, 194' Physical Review, volume 61.
5. G. Worthing, The Thermal Expansion of Tungsten at Incandescent Temperatures, Phys. Rev., 10, p, 638;1917.
6. P. N. V'yugov and V. S. Gumenyuk, High Temp. (USSR) 3:879 (1965).

Journal of Chemical Health Risks

www.jchr.org

JCHR (2024) 14(2), 279-284 | ISSN:2251-6727

7. White J L 1959 Physicochemical Measurements at High Temperatures ed. J O'M Bockris J L White and J D Mackenzie (London: Butterworths) Appendix 4.
8. L.S. Dubrovinsky, S.K. Saxena, Thermal Expansion of Periclase (MgO) and Tungsten (W) to Melting Temperatures, Phys Chem Minerals (1997) 24: 547–550
9. V. T. Deshpande and Ramrao Pawar, X-Ray Determination of the Thermal Expansion of Tungsten, Current Science , December,1962, Vol. 31, No. 12, pp. 497-499.
10. Jayant S. Shah and M. E. Straumanis, Thermal Expansion of Tungsten at Low Temperatures, Journal of Applied Physics, Vol.12, No. 9, Aug,1971.
11. Dodge, H. L., Phys. Rev., 1918, 21 (Series II), 311.
12. Goucher. F. S., Phil. Mag., 1924, 48 (Series VI), 229.
13. Saxena SK, Zhang J (1990) Thermochemical and pressure-volume- temperature systematics of data on solids, examples:tungsten and MgO. Phys Chem Minerals 17: 45–51.
14. Hiwa Mohammad Qadr, Calculation of Gamma-ray Attenuation Parameters for Aluminium, Iron, Zirconium and Tungsten, Problems of Atomic science and Technology, 2020, N5(129). Series: Nuclear Physics Investigations (74), p.60-65.
15. Drotning W. D,"Thermal Expansion of Glasses in the Solid and Liquid Phases", International J of Thermophysics, Vol. 6, No. 6, 1985.
16. DrotningWilliam.D, "Thermal expansion of solids at high temperatures by the gamma attenuation technique", Rev Sci Instrum, 50, No12, 121, 567. 1979.
17. A.S.MadhusudhanRao et.al... "Thermo physical Properties of NaCl, NaBr, NaF by Gamma Ray Attenuation Technique", J Modn Phys, Vol.4, No.2, 208-214., 2013.
18. Hubbell, J.H., Seltzer, S.M., Int. J. Appl.Radiat. Isot. 33, 1269–1290, 1995.
19. Gerward L, Guilbert N, Bjorn Jensen K and Levring H, Radiat. Phys.Chem. 60, 23-24,2001.
20. Preseren R and Korde A, Radiation Physics and Chemistry, 55, 363, 1999.
21. MadhusudhanRao A. S, et al Study of Energy Dependent γ- ray Attenuation and Determination of Effective Atomic Number and Electron Density of Sodium Halides, Journal of Applied Physical Science International. Vol. 7 (4). 199-206, March, 2017.
22. A.S.MadhusudhanRao et.al. "Thermo physical Properties of Rubidium and Lithium Halides by Gamma Ray attenuation Technique", Journal of High Temperature, Springer Link, Issue-5, 2014.
23. A.S.MadhusudhanRao et.al "Studies on Thermo physical Properties of CaO and MgO by Gamma Ray attenuation", Journal of Thermodynamics, April, 2014.
24. A.S. MadhusudhanRao et al, Determination of Photon Interaction Parameters of CaO and MgO for Multi-Energetic Photons using γ-Ray Attenuation Technique, IOSR-JAP, Volume 8, Issue 2 Ver. I, PP 103-109, Mar. - Apr. 2016.
25. PeterHindnert and W.T. Sweeny, Thermal Expansion of Tungsten, National Institute of Standards and Technology(Gov).