This Week's Citation Classic

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Hubbell J H. *Photon cross sections, attenuation coefficients, and energy absorption coefficients from 10 keV to 100 GeV.*
Washington, DC: US Government Printing Office, August 1969.
National Standard Reference Data Series Report No. NSRDS-NBS 29. 80 p.
[Ctr. for Radiation Res., Natl. Bureau of Standards, Washington, DC]

This paper reviews the principal processes—photoelectric absorption, coherent and incoherent scattering, and pair production—by which photons 10 keV to 100 GeV interact with matter. Cross sections and attenuation and energy-absorption coefficients are tabulated for selected elements Z = 1 to 92 and for some common materials. [The *SCI*® indicates that this paper has been cited over 245 times since 1969.]

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"The radiation theory group at the National Bureau of Standards (NBS) has since the late-1940s been an internationally recognized source of photon and electron transport and cross section data. Ugo Fano, one of whose works became the first NBS *Citation Classic*,[1] was through the 1950s chief of this group, then part of the NBS Atomic and Radiation Physics Division under radiation pioneer Lauriston Taylor.

"I joined Fano's group in 1951 after nearly a year as a participant in the NBS 'Junior Scientist Rotation Training Program.' My two training assignments included measuring x-ray diffraction powder-patterns, under Howard McMurdie, for the ASTM analytical-standards file, and compiling tables of compressibility factors and related properties of steam, under Joe Hilsenrath, for the National Advisory Committee for Aeronautics (precursor of NASA).

"Fano, during his tenure, insisted that an experimental program be carried on as a vital element within the radiation theory group. Thus I came on board as an apprentice to experimentalist Evans Hayward in a variety of penetration, backscattering, and angular distribution measurements spanning the photon energy range from a few keV up to 10 MeV betatron bremsstrahlung.

"In May 1952, Fano threw a party in his home celebrating the completion by Gladys White (Grodstein) of an 'unpublished' NBS report[2] which reviewed measured x-ray cross section data and state of the art theory, and provided systematic tabulations for 19 elements and four common materials. This report established the text and table format for subsequent updated versions of this material including NSRDS-NBS 29. Gladys used her maiden name (White) for her first version[2] and her married name (Grodstein) for her published version,[3] which has led to much confusion in citing her work.

"Grodstein and her immediate successor, Rosemary McGinnies (now Berger), left NBS, and I inherited the x-ray data project, following a year helping Everett Fuller establish his photonuclear data project. About this time (1963) the National Standard Reference Data System (NSRDS) was instituted, administered by the NBS Office of Standard Reference Data initially under Ed Brady and presently under David Lide, to coordinate and support existing data evaluation and compilation activities.

"One x-ray data center output, assembled with the guidance and collaboration of Martin Berger, was an invited contribution, updating and extending (to 10 GeV) the Grodstein work,[2,3] for an IAEA compendium.[4,5] NSRDS-NBS 29 is a further revision of this material, extending the tables up to 100 GeV and including a much-improved series expansion for the Compton scattering cross section for low energies where the Klein-Nishina formula is unsuitable for computation. Some more recent work in this subject area is reviewed in the collaborative (NBS, Kaman Sci., LASL, LLL, Mainz, Trondheim) efforts listed in references below.[6,7]

"The success of NSRDS-NBS 29 is due, I think, simply to the chronic and wide interdisciplinary need for x-ray interaction data in this convenient format established by Fano and Grodstein. This work probably contributed to my recent election to fellow in the American Nuclear Society."

1. **Fano U.** Effects of configuration interaction on intensities and phase shifts. *Phys. Rev.* **124**:1866-78, 1961. [Citation Classic. *Current Contents* (27):8, 4 July 1977.]
2. **White G R.** *X-ray attenuation coefficients from 10 keV to 100 MeV.* Unpublished National Bureau of Standards Report No. 1003, 1952. 95 p.
3. **Grodstein G W.** *X-ray attenuation coefficients from 10 keV to 100 MeV.* Washington, DC: US Government Printing Office, 1957. National Bureau of Standards Circular No. 583. 56 p.
4. **Hubbell J H & Berger M J.** Attenuation coefficients, energy absorption coefficients, and related quantities. (Jaeger R G, ed.) *Engineering compendium on radiation shielding.* Berlin: Springer-Verlag, 1968. Vol. 1. p. 167-84.
5. ----------. Photon atomic cross sections. (Jaeger R G, ed.) *Engineering compendium on radiation shielding.* Berlin: Springer-Verlag, 1968. Vol. 1. p. 185-202.
6. **Hubbell J H, Veigele W J, Briggs E A, Brown R T, Cromer D T & Howerton R J.** Atomic form factors, incoherent scattering functions, and photon scattering cross sections. *J. Phys. Chem. Ref. Data* **4**:471-538, 1975.
7. **Hubbell J H, Gimm H A & Øverbø I.** Pair, triplet and total atomic cross sections (and mass attenuation coefficients) for 1 MeV-100 GeV photons in elements Z = 1 to 100. *J. Phys. Chem. Ref. Data* **9**:1023-147, 1980.