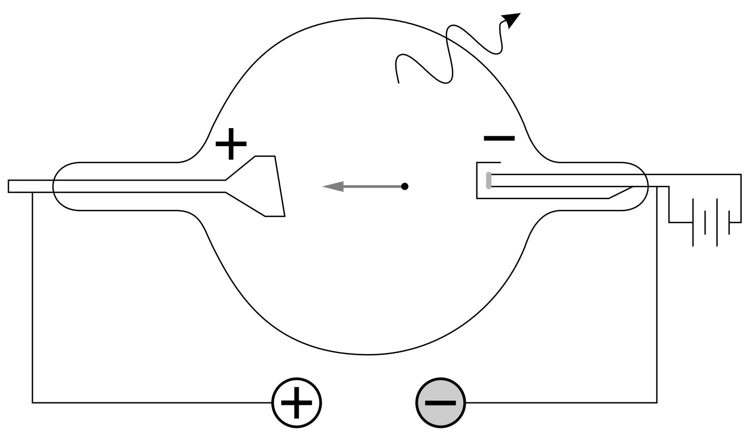
MISN-0-317

X-RAY SPECTRA



Project PHYSNET Physics Bldg. Michigan State University East Lansing, MI

X-RAY SPECTRA

by

J. H. Hetherington

Title: **X-Ray Spectra**

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Input Skills:

1. Vocabulary: X-ray (MISN-0-212); spectroscopic notation (MISN-0-244).
2. Describe shell structure and electronic configuration of atoms (MISN-0-318).
3. Determine the energy levels of hydrogen-like atoms (MISN-0-215).

Output Skills (Knowledge):

K1. Vocabulary: absorption coefficient, absorption limit, absorption edge, Bragg scattering, bremsstrahlung.

K2. Describe the production of discrete X-ray spectra.

K3. Derive the absorption law for X-rays passing through matter.

K4. State the Bragg scattering law for X-rays.

K5. Explain the nomenclature for the principle X-ray spectral lines.

Output Skills (Problem Solving):

S1. Determine the maximum energy or minimum wavelength of X-rays produced when electrons of a given energy bombard a target.

S2. Determine the absorption of X-rays of given intensity passing through a material with a given absorption coefficient and thickness.

S3. Given the atomic number Z of an atom, estimate the wavelength of the K_a line and of the K absorption limit.

External Resources (Required):

1. Weidner and Sells, *Elementary Modern Physics*, 3rd ed., Allyn and Bacon (1980). For access, see this module's *Local Guide*.
2. H. Semat and J. R. Albright, *Introduction to Atomic and Nuclear Physics*, 5th ed., Holt, Rinehart, Winston (1972). For access, see this module's *Local Guide*.

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New authors, reviewers and field testers are welcome.

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1. Study Program

Note: all references below are to WSM[1] or AS.[2]

1. Read WSM Section 4-3 (Output Skills K1 and P1) and then work Problem 1 in this module's *Problem Supplement*.
2. Read WSM Section 4-7 (Output Skills K3 and P2) and then work Problems 2 and 3 respectively.
3. Review WSM Section 5-3 (Output Skill K4) (this will not be tested in this Unit).
4. Read WSM Section 7-10 (Output Skills K2, K5, P3). Note that Fig. 7-31 is almost identical to Fig. 4-10. The principal interest in Chapter 7, however, is the discrete spectrum rather than bremsstrahlung. Question: Can discrete X-ray lines appear above vmax of Fig- 4-10? Work Problems 4 and 5.
5. Read SA Sections 10-3, 10-4, 10-5 and 10-6. SA Section 10-3 serves Output Skill K1. SA Sections 10-4 and 10-5 are interesting but not relevant to any particular Output Skill. SA Section 10-6 supplements WSM Section 7-9 and is especially relevant to K5 but gives more detail than WSM. The exam will not require knowledge of the splitting of the K_α, K_β, L_α lines, etc. Work Problem 6.

Acknowledgments

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[1] R. T. Weidner and R. L. Sells, *Elementary Modern Physics* 3rd ed., (Allyn and Bacon, Boston: 1980. For access, see this module's *Local Guide*.)

[2] H. Semat and J. R. Albright, *Introduction to Atomic and Nuclear Physics*, 5th ed. (Holt, Rinehart, Winston, New York, 1972. For access, see this module's *Local Guide*.

LOCAL GUIDE

The readings for this unit are on reserve for you in the Physics-Astronomy Library, Room 230 in the Physics-Astronomy Building. Ask for them as "The readings for CBI Unit 317." Do **not** ask for them by book title.

PROBLEM SUPPLEMENT

Note: Problems 6-9 also occur on this module's *Model Exam*.

1. An electron is accelerated through 104 V and strikes a metal target. What are the maximum energy photons obtained from the target by the Bremsstrahlung process? What is the wavelength of one of these maximum-energy photons?
2. WSM, Problem 4-42.
3. WSM, Problem 4-39.
4. WSM, Problem 7-42.
5. An element has a K absorption limit of 0.485 Å, and a K_α line of 0.560 Å. What wavelength do you expect for the L absorption limit?
6. What is the wavelength of the K_α line for ${}_{26}$Fe?
7. What electron transition corresponds to the L_α transition? (K6)
8. The absorption coefficient for 10 KeV photons in aluminum is $\mu = 67.5\,/\mathrm{cm}$. What fraction of these X-rays will be absorbed by 0.0500 cm of Al?
9. A 5 KeV electron beam strikes an Iron target. A sample of tungsten (${}_{74}$W) is exposed to the X-rays from this target. Would any of these X-rays be able to ionize electrons from the K-shell of W?

Brief Answers:

1. Max energy is 10^4 eV.

   Wavelength= $h/p = (2\pi\hbar c)/(pc) = 2\pi \cdot 2000/E = 2\pi \cdot 2000/10^4 = 1.24\,\text{Å}$

2. a. $$\begin{aligned} e^{-\mu t} &= 0.1 \\ -\mu t &= \ell n(0.1) \\ \mu t &= \ell n(10) \\ t &= (1/\mu)\ell n(10) = 2.3026/\mu = \frac{2.303}{50.6/\,\mathrm{cm}} = 0.046\,\mathrm{cm} \end{aligned}$$

   b. $I/I_0 = e^{-0.046\,\mathrm{cm}\cdot 667/\,\mathrm{cm}} = 4.73 \times 10^{-14}$

3. $e^{-\mu t} = \frac{1}{2}$

   $-\mu t = \ell n\frac{1}{2}$

   $\mu t = \ell n(2)$

   $t = (1/\mu)\ell n(2)$

   ÅÅ

4. a. $$\begin{aligned} E &= 13.6 \text{ eV}(Z-1)^2 \cdot (3/4) \\ &= 13.6 \text{ eV} \cdot (91)^2 \cdot (3/4) = 8.58 \times 10^3 \text{ eV} = 8.58 \text{ KeV} \\ \lambda &= (12.398 \text{ Å KeV})/(84.5 \text{ KeV}) = 0.147 \text{ Å} \end{aligned}$$

   b. $$\begin{aligned} E &= 13.6 \text{ eV} \cdot (12)^2 \cdot (3/4) = 1.469 \times 10^3 \text{ eV} = 1.47 \text{ KeV} \\ \lambda &= (12.398 \text{ Å KeV})/(1.469 \text{ KeV}) = 8.44 \text{ Å} \end{aligned}$$

5. Reciprocal λ (i.e. $1/\lambda$) is proportional to energy.

   $$\Rightarrow \frac{1}{\lambda_{\mathrm{K}_{limit}}} - \frac{1}{\lambda_{\mathrm{L}_{limit}}} = \frac{1}{\lambda_{\mathrm{K}_\alpha}}$$

6. $\lambda = \dfrac{2\pi\hbar c}{pc} = \dfrac{2\pi\hbar c}{E} = 2\,\text{Å}$

   $E = 13.6\,\mathrm{eV} \cdot (3/4) \cdot (Z-1)^2 = 13.6\,\mathrm{eV} \cdot (3/4) \cdot 625 = 6375\,\mathrm{eV}.$

7. An electron from the n=3 shell falls to the n=2 shell, which had to have a single vacancy present in order for the transition to occur.

8. $I/I_0 = e^{-\mu t} = e^{-(67.5)(0.05)} = 0.034$ so 96.9% abs.

9. K-absorption limit for W is approximately

   $E_{K_{limit}} \approx (13.6\,\mathrm{eV}) \cdot (1) \cdot (73)^2 \approx 65,000\,\mathrm{eV}$

   Highest energy x-ray from Fe target is 5 KeV so no ionization is expected.

MODEL EXAM

1. See Output Skills K1-K5 in this module's *ID Sheet*.
2. What is the wavelength of the K_α line for ${}_{26}$Fe?
3. What electron transition corresponds to the L_α transition? (K6)
4. The absorption coefficient for 10 KeV photons in aluminum is $\mu = 67.5\,/\text{cm}$. What fraction of these X-rays will be absorbed by 0.05 cm of Al?
5. A 5 KeV electron beam strikes an Iron target. A sample of tungsten (${}_{74}$W) is exposed to the X-rays from this target. Would any of these X-rays be able to ionize electrons from the K-shell of W?

Brief Answers:

1. See this module's *text*.
2. See this module's *Problem Supplement*, problem 6.
3. See this module's *Problem Supplement*, problem 7.
4. See this module's *Problem Supplement*, problem 8.
5. See this module's *Problem Supplement*, problem 9.