Effects of variable high voltage and emission current on X-ray energy spectrum of molybdenum.

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I. INTRODUCTION

The atomic modal has gone through several major changes throughout history. John Dalton proposed the "solid sphere" model of the atom in his 1803. He claimed that atoms are indivisible particles characterized by their mass that can be combined in whole-number ratios to make compounds. Next, in 1897, Joseph John Thomson discovered a negatively-charged particle–the electron. Thus, the atom was not indivisible; instead, it had a complex internal structure. This supported Lord Kelvin's model, which claimed that the atom was a sphere of positive charge with pockets of negatively-charged electrons. The atomic model was further refined in 1911 by Ernest Rutherford. From his famous gold-foil experiment, Rutherford concluded that atoms must have a small, dense, positively charged core–the nucleus–with the electrons orbit randomly around it. Soon after, Niels Bohr proposed his quantized shell model. Here, the electrons orbit the nucleus of fixed energy. Electrons can absorb energy from a photon and jump to a higher orbital with a higher energy level, or emit energy and jump to a lower level.

Bremsstrahlung radiation occurs when highly energetic, free electrons decelerate, moving to a lower energy level, when they contact matter. This produces a continuous spectrum of X-ray photons. Electrons penetrating deep into the atomic shell produce characteristic emission lines that peak above the continuous spectrum. These eject the innermost orbital electrons via collisions, which create gaps that the outer-orbital electrons fall into. Energetic, free electrons can be produced by an electrical voltage or current. Electrons emitted from the cathode are incident on the anode, and produce X-ray emission lines unique to the anode material.

One method of observing an X-ray spectra is by reflecting the X-rays off of a crystal. Bragg's law of refraction (Equation 1) relates the scattering angle (θ) to the wavelength (λ) of first order diffraction [1]. In this research, we use a NaCl crystal with a lattice plane spacing (d) of 282.01 pm.

$$\lambda = 2d \sin\theta \tag{1}$$

The energy of the X-ray radiation can be calculated using the following electromagnetic frequency equations: Equation 2 (where ν is the frequency and c is the speed of light)

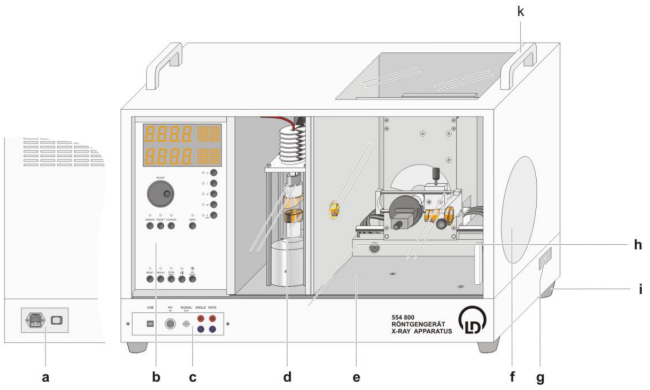

FIG. 1. 554 800 Rontgengerat X-ray apparatus, which consists of the following components: (a) main power panel, (b) control panel, (c) connection panel, (d) X-ray tube chamber, (e) experiment chamber with goniometer, (f) fluorescent screen, (g) free, (h) lock, (i) feet, and (k) carrying handles [3].

$$\nu = \frac{c}{\lambda} \tag{2}$$

and Equation 3 (where h is Planck's constant) [2].

$$E = h\nu \tag{3}$$

In this research, we investigate the x-ray energy spectrum of molybdenum X-ray tube. We observe the effects of varying the high voltage and emission current on the resulting spectrum.

II. METHOD

For this research, we use the 554 800 Rontgengerat X-ray apparatus (see Figure 1). The apparatus is controlled by a microprocessor, which controls the X-ray tube, goniometer, and Geiger-Muller counter tube [3]. The X-ray tube is a hot cathode tube with a molybdenum (Mo) anode. The anode material is $K_\alpha = 17.4$ keV and $K_\beta = 19.6$ keV with a voltage range of 0.0 kV $< U <$ 35 kV and current range of 0.0 mA $< I <$ 1 mA. The goniometer consists of two independent stepper motors to control the position of the target stage and sensor arm. It has an angular resolution of 1° across a range of $-10°$ to 170°. The NaCl crystal is placed on the target stage. The target and sensor arm can be coupled to maintain

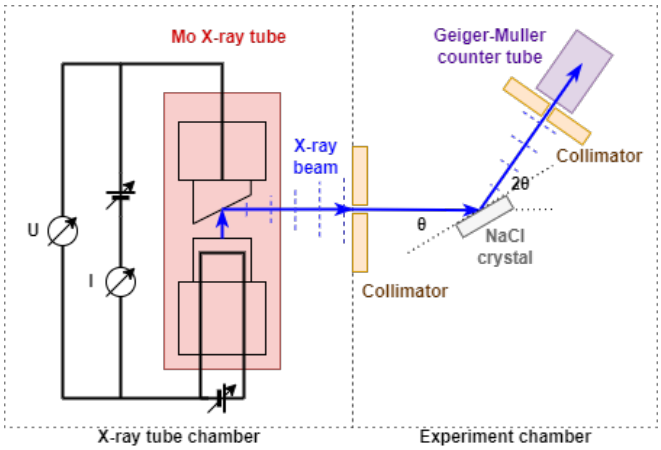

FIG. 2. Experiment setup. The X-ray beam (shown in blue) is generated by the X-ray tube with molybdenum (Mo) anode (red). The diffracted X-ray beam is collimated (orange) as it enters the experiment chamber. The beam reflects off the NaCl (gray) at an angle θ before passing through a second collimator (orange) and being absorbed by the Geiger-Muller counter tube. The counter tube is coupled to be at an angle of 2θ with reference to the horizontal X-ray beam. The emission current (I) and high voltage (V) are variable.

a 2:1 angle. The Geiger-Muller counter tube is a sensor that can count the number of incident X-rays, up to 9999 s^{-1}. The control panel allows the user to set the X-ray tube high voltage (U), emission current (I), measuring time per angular step (δt), goniometer angular step width ($\delta\beta$), and goniometer upper and lower limits (β) [3]. The NaCl crystal in Bragg configuration in combination with the counter tube comprise a spectrometer.

In this research, we are investigating the effects of the high voltage and emission current on the X-ray energy spectrum by first order Bragg reflection on an NaCl crystal. To do this, we conduct two experiments: (a) varying the high voltage at a constant current, and (b) varying the emission current for a constant voltage. The setup for these experiments is shown in Figure 2. For both experiments, the slit opening of the X-ray tube collimator is set to be 5 cm from the center of the NaCl crystal on the target stage; the Geiger-Muller sensor is then adjusted to be 6 cm from the crystal. The measuring time is set to $\delta t = 10$ s, angular step width $\delta\beta = 0.1°$, and goniometer upper limit of $\beta = 2.5°$ and lower limit $\beta = 12.5°$. The apparatus is also set to 2θ coupling between the target and sensor on the goniometer. For experiment (a), we take measurements between the goniometer limits for each $U = 15$, 20, 25, 30, and 35 keV while the maintaining a constant $I = 1.00$ mA. For experiment (b), we vary take measurements for each $I = 0.40$, 0.60, 0.80, and 1.00 mA with a constant $U = 35$ kV. We perform two trials for each experiment to cross-check the data and improve results.

	Voltage [$\pm$0.1 kV]
U_0	15.0
U_1	20.0
U_2	25.0
U_3	30.0
U_4	35.0

TABLE I. Five different voltages for the constant $I = 1.00$ mA. The X-ray photon counts are tracked from $(2.5 \pm 0.1)° \leq \beta \leq (12.5 \pm 0.1)°$ at $(0.1 \pm 0.1)°$ resolution.

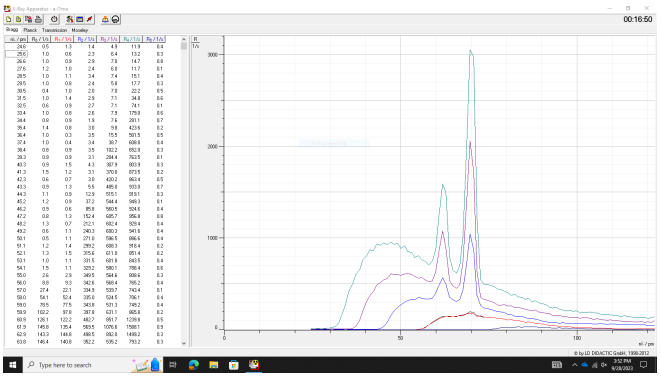

FIG. 3. Trial 1 for constant current and variable voltage. The largest curves show the larger voltages.

III. RESULTS AND DISCUSSION

In this research, we investigate the effects of varying voltage and current on the X-ray spectrum for a molybdenum (Mo) anode. We claim the following instrumental uncertainties: I is $\pm$0.01 mA, U is $\pm$0.1, β is $\pm$0.1, and t is $\pm$1.

Table I shows the five voltages used for the constant current of $I = 1.00$ mA. We complete two independent trials, measuring the X-ray spectrum for each U twice. The results are shown in Figures 3 and 3. We observe very good agreement between the two trials. The figures show that increasing the high voltage causes the Bremsstrahlung radiation spectra and emission lines to become more pronounced. The emission features are difficult to resolve at $U < 25$ kV, suggesting that the X-rays are unable to penetrate the inner orbitals.

IV. CONCLUSION

[1] W. H. S. Bragg and W. L. S. Bragg, The reflection of x-rays by crystals, Nature **91**, 477 (1913).

[2] M. Planck, Ueber das gesetz der energieverteilung im normalspectrum, Annalen der Physik **309**, 553–563 (1901).

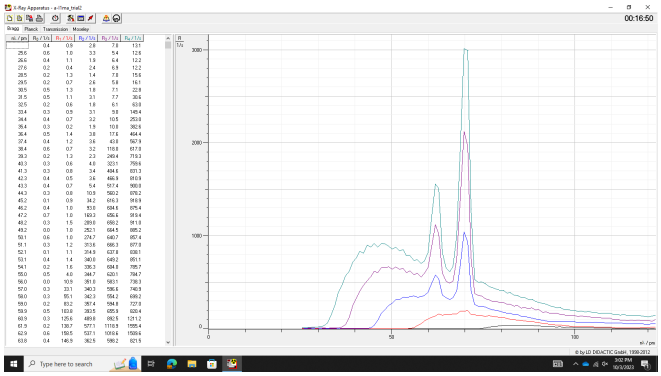

FIG. 4. Trial 2 for constant current and variable voltage. The largest curves show the larger voltages.

[3] L. D. GmbH, Instruction sheet 554 800 (2014).