New, High-Dispersion, High-Resolution X-Ray Spectrometer: Measurements of the $CrK\alpha_{1,2}$ Lines.*

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Abstract

A high efficiency, high resolution, high dispersion, low cost x-ray spectrometer is described. Although the instrument was developed primarily for space science applications it has a broad range of application for normal laboratory research problems. As an example of its performance, measurements of the $CrK\alpha_{1,2}$ spectrum are presented. The observed, uncorrected full-widths at half-maximum intensity are: $K\alpha_1$=2.09eV and $K\alpha_2$=2.67eV. Fine structure details, hitherto unreported, were also observed.

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Models[1] which account for the production of x-rays observed from celestial sources also predict the existence of discrete spectral features in the form of emission lines and absorption and re-combination edges. These features have already been observed in the solar x-ray spectrum with instruments of low to modest resolution[2].

An instrument easily adapted to the requirements of x-ray astrophysics which permits greatly increased resolution and dispersion without much loss of efficiency is shown in Fig. 1a. A conventional Johann spectrometer[3] is used with several modifications. A point source of x rays with a large cone angle, about 10°, is used to illuminate the crystal. Each ray $\vec{r}$ of the beam is defined by a horizontal divergence α and a vertical divergence ϕ. In general, the ray $\vec{r}(\alpha,\phi)$ strikes the crystal at a Bragg angle which is slightly different from that of the central ray $\vec{r}(0,0)$. The deviation from the central Bragg angle is given by

$$\sin(\theta_B+\Delta) = \sin(\theta_B+\delta)\cos\phi \qquad (1)$$

$$\text{where } \cos(\theta_B+\delta) = \cos\theta_B\cos\alpha. \qquad (2)$$

For the sufficiently small α and ϕ, Δ is given by

$$\Delta \approx \frac{\alpha^2}{2}\cot\theta_B - \frac{\phi^2}{2}\tan\theta_B. \qquad (3)$$

On the focussing circle, the polychromatic reflection pattern is concentrated into a narrow line which is conjugate to the source point. At the focus, the one-to-one correspondence between a point in the image and a point on the crystal is destroyed by the astigmatic effects of the cylindrical lens. It may, therefore, be possible for several wavelengths to contribute to the image at one point. Also, high resolution studies are made difficult by the low dispersion at the focus. This loss of spectral resolution can be avoided only by limiting the vertical and horizontal divergence of the beam to a small range of angles about the central ray (typically ±1/4°).

The basic improvements inherent in our new concept result from placing the film or detector near the crystal. Figure 1b shows the images recorded on x-ray film placed at different distances along and perpendicular to the line of the reflected central ray. The instrument was set for $CrK\alpha_1$. A mica crystal (R=13.5") which reflected CrKα radiation in 5^{th} order was used. As the distance from the crystal increases (1 through 7), both the dispersion and resolution are decreased. At the focus, Fig. 1b-5, where measurements with this type are usually made, the distinction between α_1 and α_2 is almost totally lost.

A high despersion photographic image of the $CrK\alpha_1\alpha_2$ doublet in 8^{th} order (mica) is shown in Fig. 1c. In this case the instrument was set with the central ray at an angle

slightly larger than θ_B for $K\alpha_2$. The film was replaced by a proportional counter with a pinhole aperature in front of the acceptance window. Several scans were made in the vertical direction. The data were reduced to an energy spectrum, Fig. 2, through the use of Eqn. 3. Several scans were also made keeping the detector in a fixed position close to the crystal and slowly rotating the crystal. With the difficulties inherent in the focussed image removed, the resolution is limited only by the reflecting properties of the crystal, the source intensity distribution and the size of the detector aperature. Several spectral features, hitherto unresolved even with the best techniques of two crystal spectroscopy[4,5,6], were observed. A recent three-crystal spectrometer study of the $K\alpha_1$ line by Shah and DasGupta[7] also shows similar features. The results presented in Table I are of a preliminary nature and are meant to convey the power of the technique. More precise, higher resolution spectra and their interpretation will be obtained shortly and presented elsewhere. The method of analysis is such that precision bending of the crystal is not required since any irregularities in the loci of equal Δ can be determined empirically and their effects can be incorporated into a computerized analysis.

Optimum use of the spectrometer will be possible when the proportional counter is replaced by a multi-channel array of photo-sensitive electron multiplier tubes and a

fluorescent screen. This device would then be the analog of the photographic film. Rapid scanning of the screen would determine the coordinates of each photon and a line profile can be obtained by integrating the intensity along lines of equal Δ on the screen.

The spectrometer described is ideally suited to the needs of a spacecraft borne observatory. Concentrator telsecopes[8] already in use give highly space-resolved images which are suitable source points for the spectrometer. The large acceptance angle of the instruments insures maximum efficiency.

The advice and help of Prof. K. DasGupta was of major importance in the course of this research. Mr. P. Kramer assisted us in setting up the experiment and Mr. T. Ou aided us in the recording and analysis of the data.

Table I. Full-widths at half maximum of the CrKα_1 and Kα_2 lines.[a]

α_1 (eV)					α_2 (eV)			
[4]	[5]	[6]	[7]	Present	[4]	[5]	[6]	Present
2.46	2.32	1.97	1.90	2.09	2.90	2.84	2.50	2.67

a) These are the observed values, uncorrected for resolution and line overlap.

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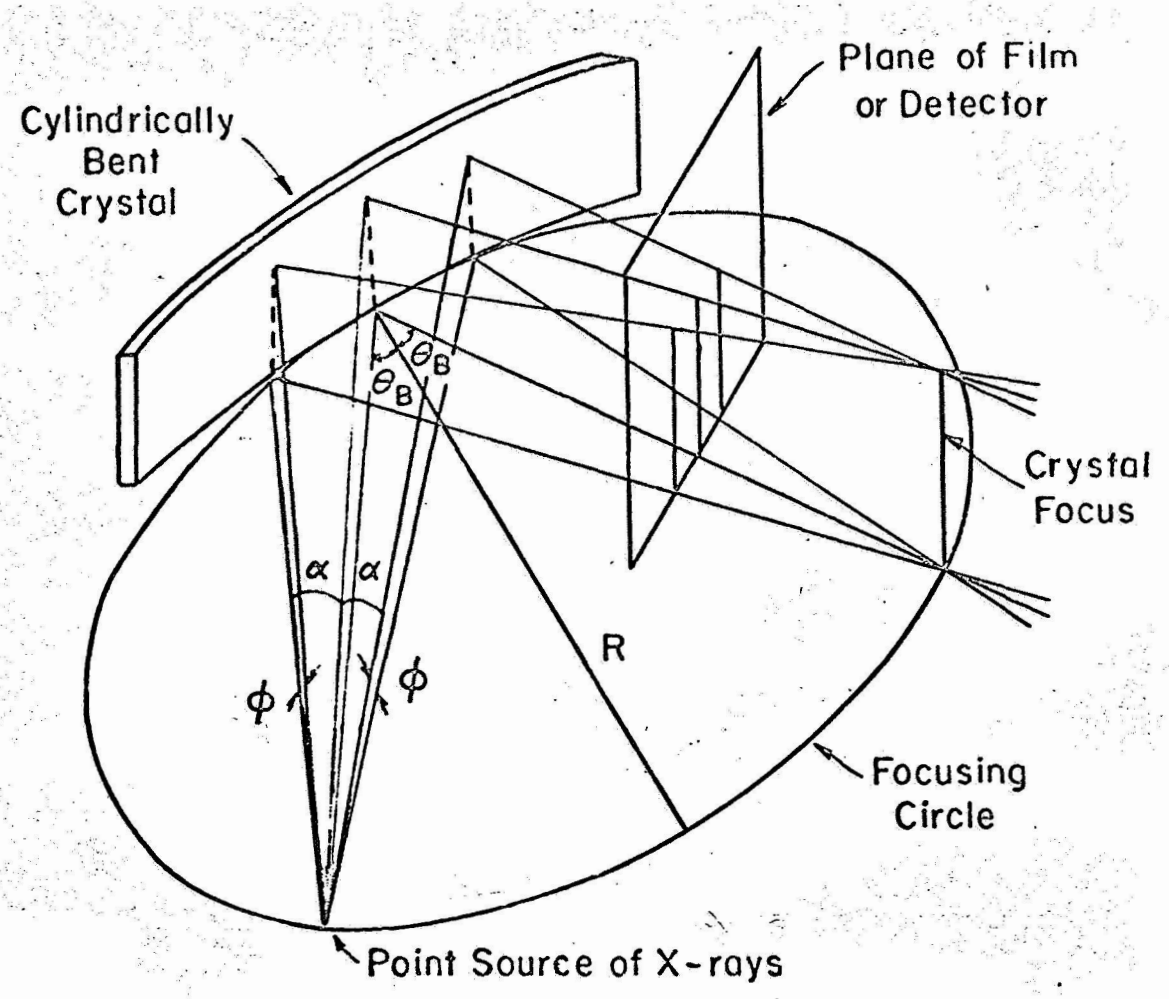
Figure Captions

Fig. 1: a) A diagram of the geometry of the present instrument;

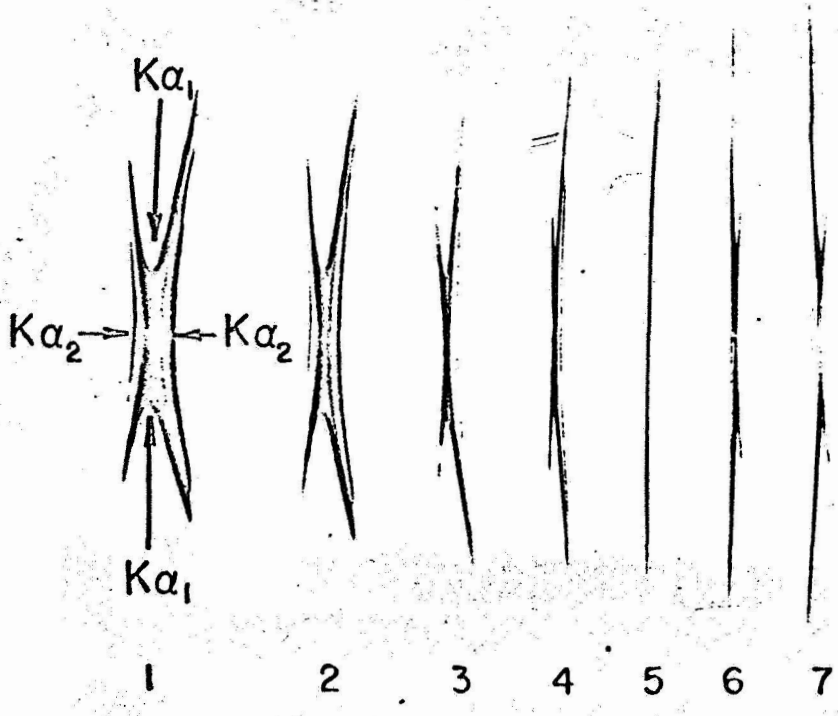
b) X-ray pictures of the $CrK\alpha_1\alpha_2$ doublet in fifth order after Bragg reflection from a cylindrically bent mica crystal. The distance between the crystal center and the film positioned as in Fig. 1 is: 1) 3.75"; 2) 4.75"; 3) 5.75"; 4) 6.75"; 5) 7.75"; 6) 8.75"; 7) 9.75";

c) An x-ray picture of the $CrK\alpha_1\alpha_2$ doublet in eighth order with the film 4.75" from the mica center. The instrument was set with the central ray at an angle slightly larger than θ_B for $K\alpha_2$.

Fig. 2: A spectrum of the $CrK\alpha_1\alpha_2$ region. The spectral features which we observed are indicated by arrows. The x-ray tube was operated at 20KV and 20ma.


Plane of Film
or Detector
Cylindrically
Bent
Crystal
θ_B
θ_B
Crystal
Focus
α α
ϕ ϕ
R
Focusing
Circle
Point Source of X-rays

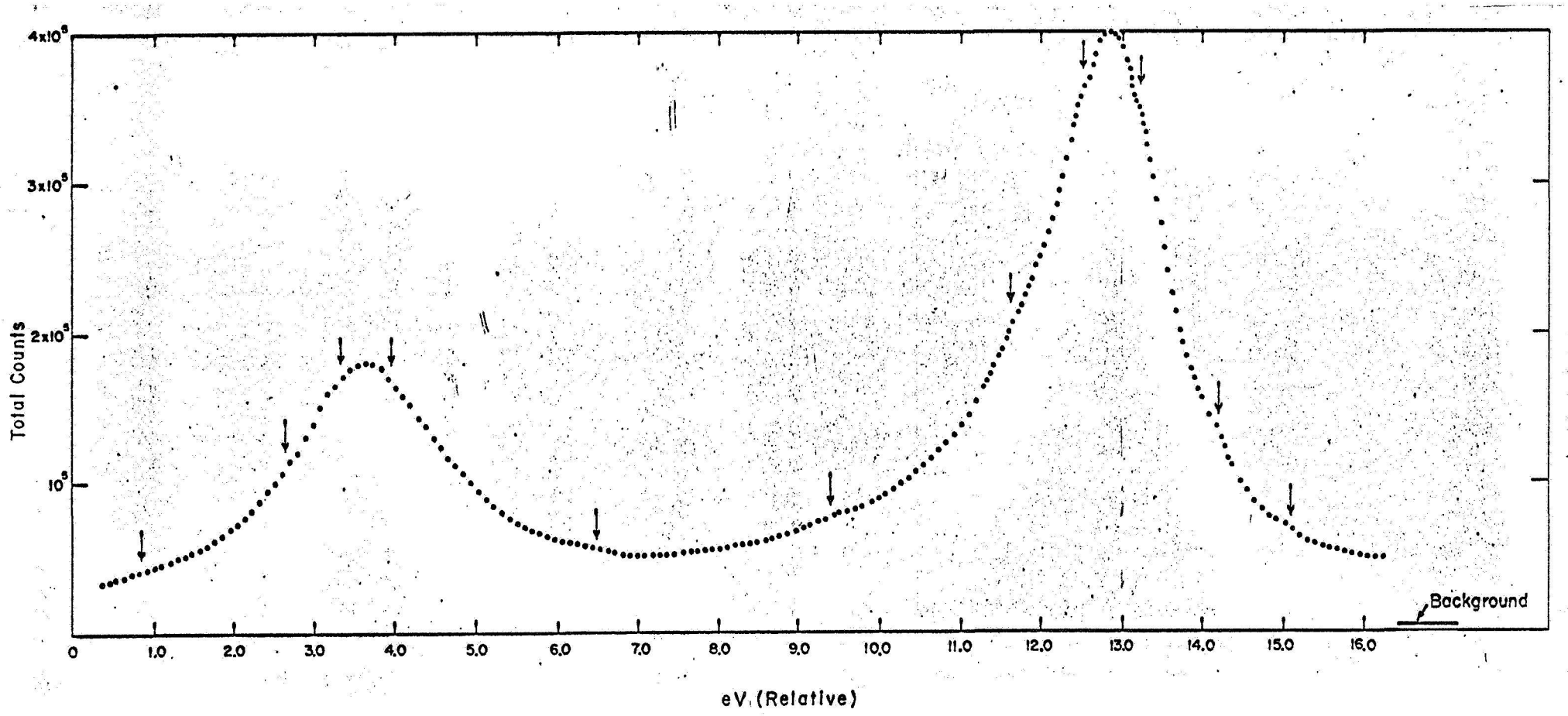
a


$K\alpha_1$
$K\alpha_2$
$K\alpha_2$
$K\alpha_1$
1
2
3
4
5
6
7

b


$K\alpha_1$
$K\alpha_2$
$K\alpha_2$
$K\alpha_1$

c


4x10^5
3x10^5
2x10^5
10^5
Total Counts
0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
13.0
14.0
15.0
16.0
eV. (Relative)
Background