freezing the melt is experienced, cooling could be speeded up by blowing a jet of cold air onto it. However, so far the author has had no difficulty in this regard. The platinum wire mount is removed and the bead is inspected under the microscope to ensure that it is wholly isotropic. If not, it is returned to the arc for a little longer. Experiment soon shows the most useful distance apart for the electrodes; the platinum can be readily softened, though it is wise to avoid this.

On formation of a glass bead this is then broken away from the wire and the refractive index determined. From this measurement the composition of the plagioclase can be found from the graph given by Foster (1955, Fig. 1).

The limitation of the method depends on the worker's capability to handle small pieces of material. Modifications will be readily apparent to anyone contemplating setting up the apparatus. We now derive our power supply by passing the mains current through a transformer-rectifier, while the platinum wire itself can be removed from its insultated holder.

I should like to express my thanks to Dr. J. P. Webb and Mr. P. S. Upton for their assistance in setting up the apparatus.

Reference

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THE AMERICAN MINERALOGIST, VOL. 43, MARCH–APRIL, 1958

A DOUBLE ARC GONIOMETER HEAD FOR CRYSTAL ORIENTATION, SAWING AND GRINDING*

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Introduction

Although the double arc goniometer head is a well known crystallographic instrument, units which possess not only adequate versatility for optical and *x*-ray diffraction orientation work but also sufficient strength to serve as sawing and grinding mounts are uncommon. Descriptions of previous instruments having these features to some degree have been given by A. E. H. Tutton (1), F. E. Wright (2) and M. J. Buerger and J. S. Lukesh (3). It is believed, however, that the goniometer

* Contribution from the Department of Mineralogy, University of Michigan, No. 212. This work has been supported financially by the Office of Naval Research and the Army Signal Corps, Fort Monmouth, N. J.

head described in this paper offers some improvements with respect to versatility, ruggedness, and accuracy, especially for the preparation of oriented specimens from large crystals of relatively hard materials. Because the instrument is designed primarily for relatively large boule type crystals, the translation motions usually employed on goniometer heads have been omitted.

The instrument has been in satisfactory operation for a period of approximately two years. A total of about 40 oriented prisms of various shapes have been accurately prepared (tolerance = 15 minutes of arc or less) from materials such as boules of silicon, strontium titanate and synthetic ruby, and crystals of quartz, periclase and microcline.

Goniometer Head Description

The overall height of the unit and its greatest width are each approximately $2\frac{1}{2}$ inches. Steel is used for all components. All straight surfaces are either milled or ground flat and parallel. Moving and guide arcs are lathe machined from cold rolled round stock. All fixed parts of the instrument are secured with steel flathead screws. Steel to steel friction clamp mechanisms or set screws are provided for locking all moving parts.

The goniometer head consists of the following basic parts: (1) a solid rectangular top section, $1\frac{1}{8}\times\frac{7}{8}\times\frac{7}{8}$ inches, which carries one set of arcs and contains a $\frac{3}{8}$ inch diameter vertical central shaft opening to receive detachable specimen holders of various designs. The latter may be secured at any desirable position by means of a set screw lock. Sealing wax, Plaster of Paris, solder and various quick drying organic cements have been successfully used for mounting crystals in specimen holders; (2) a center section of rectangular U-shaped cross section which carries a set of guide arcs parallel to those of the top section and a second set oriented at right angles to those of the top section. The dimensions of the side plates of the center section are $1\frac{9}{16}\times 1\frac{1}{8}\times\frac{1}{8}$ inches and those of the base plate $1\frac{1}{8}\times 1\frac{1}{8}\times\frac{3}{8}$ inches; (3) a base section, also of U-shaped cross section, carrying a set of guide arcs to receive those of the center section and having a $\frac{3}{8}$ inch diameter central shaft opening in the base plate coaxial with the hole of the top section. The base hole is used for mounting the assembled goniometer head on orienting, sawing or grinding equipment and also permits a 360° rotation of the head about the mounting axis. An allen head set screw is provided for locking the goniometer head to a shouldered spindle. The dimensions of the side plates of the base section are $1\frac{11}{16}\times 1\frac{1}{2}\times\frac{1}{8}$ inches, and those of the base plate are $1\frac{11}{16}\times 1\frac{3}{8}\times\frac{3}{8}$ inches.

Both sets of arcs are designed for a 45° traverse about a common center $\frac{7}{8}$ inch above the top surface of the top section. The width of all arcs is $\frac{1}{8}$ inch. Both sets of arcs are manipulated by rack and pinion drives.† The racks, standard 48 pitch $\frac{1}{8}\times\frac{1}{8}$ inch stock, are attached to the underside of the top and center sections of the instrument with steel flathead screws. The undersides of the sections are filed to the proper curvatures with respect to the common center point and the racks are bent to this same curvature. The pinion shafts, $\frac{3}{16}$ inch diameter 48 pitch pinion wire, are provided with fixed turning knobs at one end and threaded locking knobs at the other. This type of assembly permits the vertical sides of the center and base sections to be clamped against the sides of the top and center sections, respectively, thereby providing an effective locking action on arc movement. An operating clearance of approximately 0.0005 inch is provided between the vertical sides of the respective sections. Clearance adjustment may be made by placing shims under the arcs. All components of the goniometer head have been nickel plated to prevent rust.

Calibration of arc movement may be carried out optically by attaching a mirror to the specimen mount and reflecting a collimated point source of light upon a calibrated screen. The pinion knobs may then be divided to read in degrees of arc rotation about the common center point.

Some backlash is inherent in the gearing mechanism due to the necessity of bending the racks to their respective curvatures. However, with proper calibration and care in operation, the system operates well and has the advantage of being both cheap and easy to construct. The construction cost of the goniometer head is approximately $200.

Fig. 1 provides a view of the assembled goniometer head with a specimen holder. Included in the photograph is a typical crystal boule and some oriented cut specimens.

Fig. 2 shows the goniometer head mounted on a Laue back reflection *x*-ray camera. Most orientation work on boule crystals must be carried out by *x*-ray diffraction since they generally lack crystallographic surfaces suitable for optical orientation. Fig. 2 provides a more detailed view of the rack and pinion gearing and also shows the adapter coupling used for mounting the goniometer head on a standard two circle optical goniometer (see lower left of photograph).

The technique used to orient crystals by back reflection *x*-ray diffraction consists of photographing diffraction patterns on 3×4 inch sections of Kodak no-screen *x*-ray safety film with an intensifying screen backing used in the film holder. A special punch is used to produce a precision hole at the center of the film in order to insure accurate and reproducible positioning of the film around the *x*-ray collimating tube. A

† Rack and pinion stock was obtained from the Chas A. Strelinger Co., Detroit, Mich.

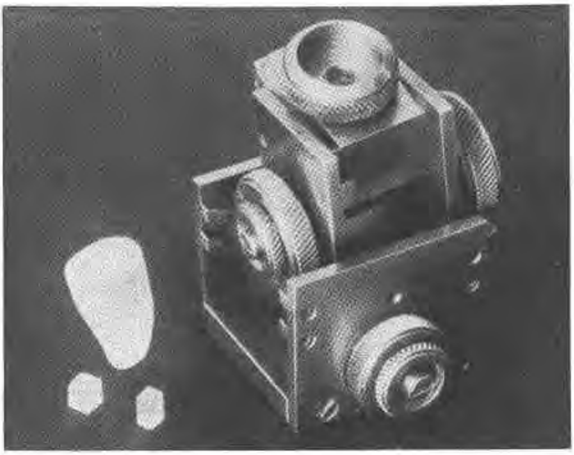

FIG. 1. A view of the double arc goniometer head. Included in the photograph is a typical crystal boule and some oriented cut specimens.

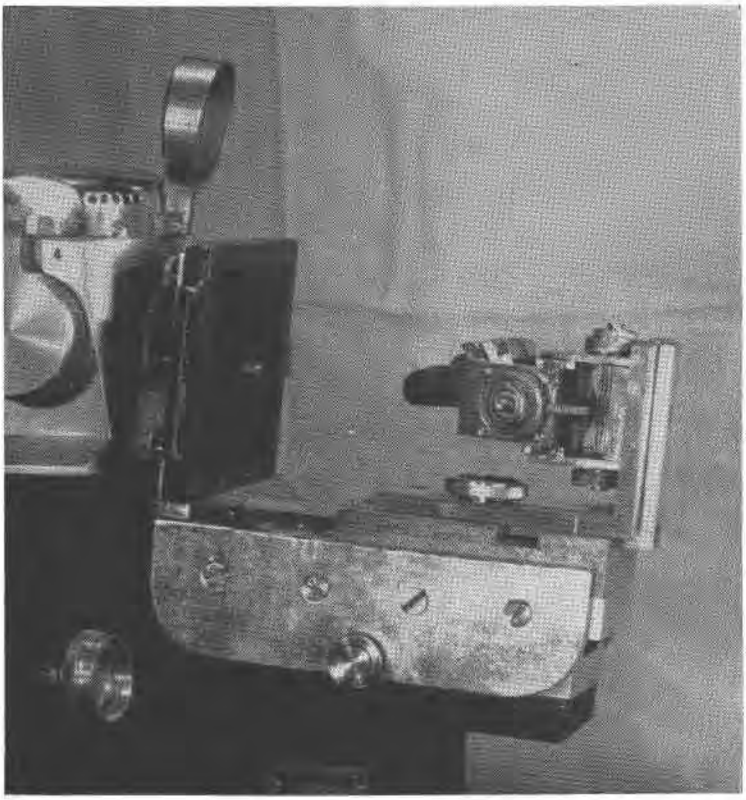

FIG. 2. A view of the goniometer head mounted on a Laue back reflection camera.

fiducial pinhole was cut into one corner of the opaque paper front of the film holder to insure correct correlation between diffraction pattern photographs and crystal orientation.

A copper target *x*-ray tube operated at 30 KV and 15 MA produces a satisfactory diffraction pattern with a 10 to 15 minute exposure. A collimating aperture of $\frac{1}{32}$ inch was used. Orientation of single crystals to within 15 minutes of arc usually can be accomplished with five or six exposures. The first one or two patterns establishes the orientation of the crystal with respect to the *x*-ray beam. Another one or two are required to bring the specimen to within 1° of the desired orientation, and a final one or two to reduce the error to less than 15 minutes.

If the specimen possesses features such as crystal or cleavage faces, preliminary orientation frequently can be made by crystallographic inspection with light reflected from these surfaces. When such pre-orientation is possible, final orientation by *x*-ray diffraction can usually be done with two or three exposures.

Goniometer adjustments are determined by placing films over a calibrated net. The latter consists of a section of plate glass showing a series of concentric circles centered on a combination orthogonal and hexagonal axial system. The increase in radius for each successive circle is equivalent to a given number of degrees of arc for a given crystal to film distance. Illumination of the net is from behind. For all films except that of the final orientation, only a short fix and quick water rinse are required prior to inspecting the photographed diffraction pattern.

After the orientation of a crystal specimen is completed and the arcs are locked, the goniometer head, with specimen undisturbed, may be transferred directly to a diamond cut-off saw or grinding equipment. An angle plate type of mount for the goniometer head as shown on the back reflection camera of Fig. 2 also serves as an excellent sawing or grinding mount, especially since the principal axis can be mounted either horizontally or vertically. Saws and grinders equipped with accurate rotary work tables permit several oriented cuts to be made with a single orientation of the crystal. For equipment requiring a spindle type of mounting, for example, the grinding apparatus described by R. M. Denning (4), the goniometer head may be directly fastened through the central shaft opening in the base plate.

The writer gratefully acknowledges the assistance received from Prof. R. M. Denning in designing the goniometer head and for critically reading the manuscript.

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PRESIDENT'S AWARD FOR DISTINGUISHED CIVILIAN SERVICE

In ceremonies at the White House on January 27, 1958, Dr. Sterling B. Hendricks was one of five recipients of the first President's Award for Distinguished Civilian Service. The following citation was read: "His discoveries in soil clays, phosphate minerals, radioisotopes, plant physiology and fundamental chemistry make him one of the most distinguished and honored scientists of our time."

Dr. Hendricks is Chief Chemist, Mineral Nutrition Laboratory, Soil and Water Conservation, Beltsville, Md. He has been a Fellow of the Mineralogical Society of America since 1940, and served as its President in 1954.