

g-z index

February 3, 1928

My dear Mr. Morse:

This morning I had an opportunity to consult the President as to the wisdom of sending copies of your Bulletin No. 1 of the Crystal Structure Laboratory to Mr. Arnett and Mr. Thorckelson. He said he thought it would be better not to send it at this time. The officers of the Board have under informal consideration the project for expansion of the work in Physics which includes provision for the work in crystal structure, but the time has not yet come to take the action that you contemplated.

Mr. Haynes says that he has been approaching persons with a view to interesting them in the crystal structure work, but as yet has no definite results to report. He is genuinely interested and will continue to seek support.

Yours cordially,

FREDERIC C. WOODWARD

Mr. J. K. Morse
Department of Physics
Faculty Exchange

FCW*L

John

February 3, 1938

My dear Mr. Morse:

This morning I had an opportunity to consult the President as to the wisdom of sending copies of your Bulletin No. 1 of the Crystal Structure Laboratory to Mr. Arnott and Mr. Thorpe. He said he thought it would be better not to send it at this time. The officers of the Board have under informal consideration the project for expansion of the work in physics which includes provision for the work in crystal structure, but the time has not yet come to take the action that you contemplated.

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Yours cordially,

FREDERIC C. WOODWARD

Mr. J. K. Morse
Department of Physics
Faculty Exchange

FCW:L

M.M.

The University of Chicago

Ryerson Physical Laboratory

January 27, 1928.

Frederic Woodward, Vice President.

University of Chicago.

Dear Mr. Woodward,

Enclosed please find a copy of a letter from Mr. Laing in regard to the publication of Bulletin No. I of the Crystal Structure Laboratory. As you suggested I took the matter up with Mr. Haynes shortly after the first of the year and he was very enthusiastic about the development scheme therein set forth. as it gave him an opportunity to approach people for small amounts to get them interested in the University. So far as I know, however no funds have come in through Mr. Haynes efforts.

At Mr. Laing's suggestion, I have gone to work to complete the bibliography and have had a stenographer working with me on it since the first of the year. Furthermore, I have gone out myself after the scholarships contemplated in the Bulletin and have approached the following people, Mrs. Geo. E. Haskell, Evanston; Mr. George Pollock, Vice President of the Nugent Steel Foundry, Miss Nelle Hall and Mrs. Albert Sherer kindly offered to appeal to Mr. Charles Swift.

As I have exhausted all my copies of the Bulletin, I am having 25 new copies made to send out to other prospective donors who know me personally. In this connection I discussed with Mr. Gale the matter of tuition and he tells me that the students receiving the Research Assistantships would have to pay two hundred and eighty dollars of the thousand dollars received on the Assistantships. Since it was my intention that this thousand dollars was to be clear for their living expenses I would like to revise the Bulletin and raise the amount of the Research Assistantships in Crystal Structure from one thousand to twelve hundred and fifty dollars to cover this tuition charge.

The University of Chicago

Western Biological Laboratory

January 27, 1938.

Enclosed please find a copy of a letter from Mr. Loring in regard to the publication of Bulletin No. 1 of the Crystal Structure Laboratory. As you suggested I took the matter up with Mr. Loring shortly after the first of the year and he was very enthusiastic about the development scheme therein set forth. As it gave him an opportunity to approach people for small amounts to get them interested in the University. So far as I know, however, no funds have come in through Mr. Loring's efforts.

At Mr. Loring's suggestion, I have gone to work to complete the bibliography and have had a stenographer working with me on it since the first of the year. Furthermore, I have gone out myself after the scholarships contemplated in the Bulletin and have approached the following people, Mrs. Geo. E. Haskell, Evanston, Mr. George Follock, Vice President of the Regent Steel Foundry, Miss Nellie Hall and Mrs. Albert Sherer kindly offered to speak to Mr. Charles Swift.

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The University of Chicago

Ryerson Physical Laboratory

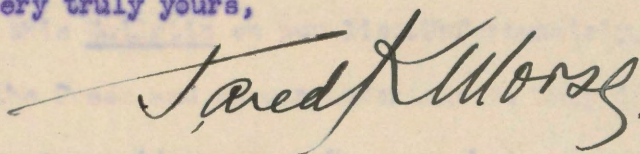
-2-

Professor J. K. Mason

Any suggestion that you would care to make in connection with this Bulletin would be very gratefully received. It is my intention to send copies to both Mr. Arnett and Mr. Thorkelson in New York provided this does not interfere with any plans you or President Mason have with respect to them.

With best regards, I am,

Very truly yours,



J.K.M./M.F.

The University of Chicago

Reginald E. Snodgrass

January 24, 1933

-2-

Professor James K. Hays
Enclosed suggestion that you would care to make in connection with this Bulletin

would be very gratefully received. It is my intention to send copies to both

Mr. Arnett and Mr. Thorpe in New York provided this does not interfere

with any plans you or President Mason have with respect to them. I am,

Very truly yours,

With best regards, I am,

Very truly yours,

J.K.M.M.P.

(COPY).

December Twenty Fourth.
1 9 2 7

January 24, 1928.

Professor Jared K. Morse
Faculty Exchange. President
Chicago.

Dear Mr. Morse.

The Board of University Publications met on Saturday morning and approved the publication of your proposed Bulletin of the Crystallographic Laboratory of the Department of Physics, University of Chicago, provided satisfactory financial arrangements could be made. All the members of the Board realized the importance of this work and want this Bulletin on our list. Unfortunately, however there are no funds available at the Press and we can undertake it only if the cost of manufacture is provided from some outside source. Have you had an opportunity of seeing Mr. Haynes and is he convinced that he could not find a wiser investment of his funds than this Bulletin. You will remember that the cost of manufacturing Bulletin number 1, (with additional material as far back as 1912) would be about eight hundred dollars.

I shall be glad to hear from you as soon as you have any information on the question of the possibility of financing the work. In the meantime I will keep here that part of the manuscript which you left with me.

Sincerely yours,

Signed Gordon J. Laing.

(copy).

January 24, 1938.

Professor Jared K. Morse
Faculty Exchange.

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Sincerely yours,

Signed
Gordon J. Loring.

The University of Chicago

Ryerson Physical Laboratory

December Twenty Fourth.

1 9 2 7

M. M. for ^{his} information

Return to
F C W

923

Fredric Woodward, Vice-President
University of Chicago.

My Dear Mr. Woodward,

Enclosed please find a copy of the first part of the Bulletin of the Crystallographic Laboratory which I discussed with you last Thursday. Following your suggestion I have submitted the manuscript to Mr. McFarland of the University Press for estimates on the cost of printing which will be ready the latter part of next week. I have also had ten copies hektographed and hope to use these on the two prospects I mentioned to you during the holidays.

When the estimates from the Press are at hand to discuss with Mr. Haynes the best methods of approaching prospective donors.

h

Thanking you for your interest in this matter and wishing you a Merry Christmas, I am

Sincerely yours

Jared K. Wilson.

Handwritten: Mr. Wm. H. ...
822

The University of Chicago
Neurological Laboratory
December Twenty Fourth
1925

Frederic Woodard, Vice-President
University of Chicago.

My dear Mr. Woodard,

I enclose please find a copy of the first part of the Bulletin of the
Neurological Laboratory which I discussed with you last Thursday. Following
your suggestion I have submitted the manuscript to Mr. Matthews of the
University Press for estimates on the cost of printing which will be ready
the latter part of next week. I have also had ten copies photographed and hope
to use these on the two papers I mentioned to you during the holidays.

When the estimates from the Press are at hand I discuss with Mr. Rogers
the best methods of approaching prospective donors.

Thanking you for your interest in this matter and wishing you a Merry
Christmas, I am

Sincerely yours

Handwritten signature: Frank M. ...

BULLETIN. No. 1. 1926-1927.

The Crystallographic Laboratory, Department of physics, University of Chicago.

Henry Gordon Gale, Chairman.

Jared Kirtland Morse, Research Associate.

1. Introduction.

The Crystallographic Laboratory was first made available for students of Chemistry, Geology, Physics and others interested in the structure of crystals in the Summer Quarter of 1926. At this time also, a series of lectures in the theory and practice of x-ray crystal analysis were given, in order to provide a background for experimental investigation in the Laboratory. The attendance at these lectures was highly gratifying as between forty and forty-five graduate students registered for or visited the course. Following these lectures in the autumn, several pieces of investigation were started. Since this time productive work has actively gone on in this Laboratory and more adequate space and apparatus have been obtained. At present, the Crystallographic Laboratory is seriously handicapped by lack of funds for salaries and fellowships. The purpose of this Bulletin is to give an account not only of the scope of the present work of the Laboratory but also to outline its development program and follow this with a bibliography of the field of Crystal Structure and its applications in research and industry in order that the work and aims of the Crystallographic Laboratory may become better known and receive the support to which it is entitled.

This Bulletin is divided into two parts. Part I. is a brief account of the work and program of the Crystallographic Laboratory. The facilities offered by the Laboratory are first described, the scope of the problems outlined and a tentative program of development presented. Reprints of the scientific contributions of the Laboratory which have been published to date will form the fifth and closing section of this part of the Bulletin. The second part is a Bibliography covering the whole field and brings out clearly the importance of this new branch of Physics in both research and industry.

This new field of investigation — the x-ray analysis of crystals — is one of the most fascinating of the developments of modern Physics. Its method of attack on the problem of the structure of matter was first developed in 1913 one year before the outbreak of the Great War. Since that time its rise has been rapid. In spite of the large amount of work which has already been accomplished in this field the amount of work remaining to be done is enormous. In general the importance of this field of work has been better recognized in Great Britain and on the Continent than in the United States. Although American physicists such as A.W.Hull, Ancel St. John, W.P.Davey, L.W.McKeehan and R.W.G.Wyckoff have done much of the pioneer work. In England the Royal Institution is entirely devoted to crystal analysis and on the Continent especially in Germany there are a number of Institutes devoted to the study of crystals. There is no reason why the United States should lag behind in organized investigation in this field and the University of Chicago in virtue not only of its geographical location but also in respect to the opportunities for cooperative research which it offers is the logical place for this new development.

2. The Facilities Offered by the Crystallographic Laboratory.

(a) Laboratory Space.

The Crystallographic Laboratory has, at present, space available for three full time investigators in addition to the regular staff. There is a large light laboratory on the second floor of the Ryerson Physical Laboratory equipped for x-ray work. The majority of the x-ray diffraction apparatus is concentrated in this laboratory and is so designed that it can be continuously operated all night without attention. This leaves the day-time free for the preparation of crystal sections, the construction of new apparatus, the development, measurement and interpretation of photographs and obviates any injury to the investigators either from x-ray burns or the more insidious and little known injurious physiological effects produce by continuous exposure to secondary x-rays which tend to produce anaemia. In addition to this laboratory there is a combined constant temperature and dark room in the basement for growing crystals and photographic work. In addition and adjoining the large laboratory is a private laboratory for the staff consisting of two rooms. One an office and goniometer and balance room and the other a combination dark room and research laboratory for work with long x-rays.

(b) Equipment.

The Crystallographic Laboratory has at present

(1). A universal x-ray spectrometer for obtaining diffraction photographs by the methods of the rotating crystal, Laue spots and the powder method of Debye and Scherrer. It is operated with air-cooled Coolidge tubes of tungsten and molybdenum and was built in the Ryerson Physical Laboratory.

(2). A universal type Muller x-ray spectrometer built by Hilger and Co of London and operated with a Scheerer tube for long wave length investigations with the radiations from iron and copper.

(3). An x-ray diffraction apparatus for use with powders by the method of Siemens-St. John operated with a water cooled molybdenum tube. This apparatus is especially well adapted for the investigation of industrial problems such as plant control in the heat and mechanical treatment of materials and qualitative x-ray analysis of samples.

(4). A General Electric x-ray diffraction apparatus for the investigation of powdered materials and metals is on order and delivery is promised for December 1927.

(5). Funds are also available for the purchase of a high grade two circle goniometer which will be ordered whenever investigations requiring it are ready to be put under way.

(c). Lectures and Laboratory Instruction.

Two series of lectures are presented twice each every other year at the Laboratory and laboratory instruction in the technique of the x-ray analysis of crystals is offered in the Autumn, Winter and Summer Quarters of each year. The first of these courses is an introduction to the general field of Molecular Physics and the Structure of Matter and the second takes up in detail the theory and practice of Crystal Analysis. It is planned to supplement this last course by a third series of lectures on the Structure of Crystals in which the results of crystal analysis will be outlined and critically discussed as soon as circumstances will permit. The following short outlines of the main headings of these two courses gives an idea of the ground covered in these lectures.

(1) Molecular Physics and the Structure of Matter.

- I. Introduction.
- II. The Meaning of Science.
- III. The History of Science.
- IV. Kinetic Theory of Gases - The Equation of State - Pressure in a Gas - Specific Heats.
- V. The Theory of Probability - The Method of Least Squares and Their Application to Molecular Problems.
- VI. The Viscosity of Gases and the Effective Diameter on Collision of Molecules.
- VII. The Dynamics of Charged Particles.
- VIII. Introduction to the Quantum Theory.
- IX. Crystal Structure and the Size of Atoms, Ions and Molecules.

(2) X-Ray Crystal Analysis.

- I. Introduction to Crystallography.
Definitions, Elements of Symmetry, Indices of Crystal Faces, Crystal Systems and Classes.
- II. The Geometrical Theory of Crystal Structure.
Space Lattices Point Groups, Space Groups.
- III. Introduction to X-Rays.
Theory of the Crystal Grating, Determination of the Lattice Constant of Sodium Chloride, Relative Determination of X-Ray Wavelengths, Compton's Absolute Determination of X-Ray Wavelengths, Design of X-Ray Tubes, Filters Effects of X-Rays on the Photographic Plate.
- IV. The Determination of Crystal Structure by Reflection from Single Crystals.
- V. The Powder Method of X-Ray Analysis.
- VI. The Determination of Crystal Structure from Laue Photographs.
- VII. Methods of Growing Crystals.
- VIII. Applications of X-Ray Crystal Analysis to Various Problems.

Both these series of lectures are given four days a week, three days being devoted to lectures and the fourth to a general discussion of the ground covered.

(3). Laboratory Instruction in Crystal Analysis.

This course is designed as an introductory course to research in crystal structure and it follows the lecture course in the X-Ray Analysis of Crystals. No definite hours in the laboratory are assigned and not more than four applicants are accepted for any one term. The student first redetermines the structure of a known simple crystal (cubic or hexagonal) by the reflection method and the method of Laue spots. In this way he gains first hand knowledge of growing crystals, identifying faces, cutting sections and taking and interpreting diffraction photographs. In some cases the structure which he obtains by these two methods he checks by means of powder photographs. The results of this work is incorporated in a typewritten report in the form of a scientific paper. At the completion of this work he is ready to take up original investigations of one of the simpler of the many problems in this field.

3. Program of Investigation of the Crystallographic Laboratory.

The field of Crystal Structure can be conveniently divided into the following sections.

I. Technique.

- A. Rotating Single Crystal Methods.
- B. Powder Methods of Crystal Analysis.
- C. Method of Laue Spots.
- D. X-Ray Goniometry.

II. The Crystal Structure of the Elements.

- A. The Space Lattices of the Elements.
- B. The Production of Single Crystals of the Metals and Elements.
- C. Atomic Structure and Dimensions.
- D. The Effect of Mechanical and Heat Treatment on Metals.
- E. The Structure of Alloys and Intermetallic Compounds.
- F. The Reflection of Electrified Particles from Crystals.

III. Inorganic Crystals.

- A. Ionic Lattices and the Structure of Anhydrous Compounds.
- B. The Growing of Single Crystals from Solutions.
- C. Allotropy.
- D. Mixed Crystals.
- E. Valence.
- F. Ionic Dimensions.
- G. The Crystal Structure of Hydrates.
- H. The Structure of Colloids.

IV. Organic Crystals.

- A. The Determination of the Molecular Lattices of Aliphatic Compounds.
- B. Molecular Structure.
- C. Optical Activity and the Structure of Optically active Compounds.
- D. The Structure of the Benzene Ring.
- E. The Determination of the Molecular Lattices of Aromatic Compounds.

Work is now being carried on in the Crystallographic Laboratory in each one of the main branches of the field outlined above and already fundamental contributions have been published in the majority of these sections. A brief account of the work done to date is herewith presented and reprints of the papers already published will be found at the end of this part of the Bulletin.

2. Program of Investigation of the Crystallographic Laboratory.

The field of Crystal Structure can be conveniently divided into the following sections.

I. Techniques.

- A. Rotating Single Crystal Methods.
- B. Powder Methods of Crystal Analysis.
- C. Method of Line Spots.
- D. X-Ray Fluorescence.

II. The Crystal Structure of the Elements.

- A. The Space Lattices of the Elements.
- B. The Prediction of Single Crystals of the Metals and Elements.
- C. Atomic Structure and Dimensions.
- D. The Effect of Mechanical and Heat Treatment on Metals.
- E. The Structure of Alloys and Intermetallic Compounds.
- F. The Prediction of Restricted Particles from Crystals.

III. Inorganic Crystals.

- A. Ionic Lattices and the Structure of Anhydrous Compounds.
- B. The Growth of Single Crystals from Solutions.
- C. Allotropy.
- D. Mixed Crystals.
- E. Valence.
- F. Ionic Dimensions.
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- H. The Structure of Colloids.

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I. Technique.

(1). The 'Doughnut' Filament Transformer.

An extremely cheap, efficient and easy to construct type of air insulated transformer for heating filaments kept at high potentials has been developed in the Crystallographic Laboratory to take the place of the expensive and unsatisfactory commercial oil immersed, filament transformers now on the market. The core of these 'Dough-nut' transformers consists of 25 pounds of soft annealed "stove pipe" wire wound in a torus whose inside diameter is approximately 14". This is covered with friction tape and wound not too closely with No. 18. cotton covered copper wire. This forms the primary. The secondary consists of another torus of the same size as the primary and the same inside diameter made of No. 8 rubber covered copper wire, the total resistance of this secondary being equal to the total resistance of the filament circuit of the X-ray tube to be used. These two coils, the primary and the secondary are mounted so that their equatorial planes are mutually perpendicular and so that the primary passes through the center of the secondary. These simple transformers will stand any amount of rough treatment without burning out and are in every way satisfactory. They are now in use through out the Ryerson Physical Laboratory.

(2) A Mould for Casting Cylinders of Fine Powders.

In powder analysis by the method of Debye and Scherrer, it has been usual to employ small tubes of special glass, celluloid or collodion to keep the powder in place while the exposure is in progress. These container when of glass increase the exposure time and when made of materials containing carbon scatter the x-rays and cause considerable general blackening on the photographic plate. To obviate these difficulties, a method of casting these powders into cylinders approximately 0.075 cm. in diameter and 1.5 cm. in length in place in the center of the Debye camera has been worked out in the Crystallographic Laboratory. Figur One shows a cross section of the mould used. A little shellac is used to make the powder base marked (1) in the figure tacky so that the foot of the cylinder will adhere to it. The mould (2) is then screwed down tight and filled from the top with the fine powder care being taken to prevent too much pressure which would cause the crystalline particles to orient themselves. When the mould is full the plunger (3) is set firmly with a set screw (4). The mould is then raised by means of the nut (5) on the thread (6). The plunger is then carefully removed and the whole mould taken off from the brass base leaving the powder cylinder without any container standing vertically in the center of the camera.

(3). A Grinding Goniometer.

In the reflection method and especially in the method of Laue spots, thin plane crystal sections are required cut parallel to a given plane having simple indices. It often happens that the planes required do not occur naturally on the crystals grown. The accurate cutting of these sections and the grinding of them to the required thinness by hand is a difficult and tedious job. A grinding goniometer of suitable design reduces the time and increases the accuracy considerably. Such an apparatus was designed by Mr. W. King Hubbert in the Crystallographic Laboratory in the Spring of 1927 and its construction was well along by the beginning of the Summer. Unfortunately Mr. Hubbert's funds gave out and he was forced to go into industrial work to earn sufficient money on which to live while he continues his investigations of which this instrument is a preliminary part. He expects to be able to continue his work in 1928. This case is typical of the spirit of most of the men interested in this field and illustrates the need of Fellowships to enable such men to carry on their work.

II. The Crystal Structures of the Elements.

A. The Space Lattices of the Elements.

(1). Boron.

In the Summer of 1926, preliminary experiments in which Prof. W.P. Jessie, Of Lehigh University collaborated were made by the method of Debye and Scherrer on powdered boron. Boron crystals were obtained from Eimer and Amend, these were powdered in an agate mortar and an attempt was made to cast them in the mould described above but without success as the powdered boron was so hard that it abraded the brass lining of the mould and could not be removed. Fine collodion cylinders were next prepared, filled with the boron powder and exposed to the radiation from a molybdenum tube. A diffraction pattern was obtained in this way on which six diffraction rings were easily discernable. As the boron used in these experiments was known to be somewhat impure, it was decided to attempt to prepare pure metallic boron in the Laboratory.

In the Winter of 1927 an attempt was made to prepare chemically pure boron. Mr. Frankel collaborated in these experiments. The method employed was to reduce chemically pure boric acid to metallic boron by means of an "atomic hydrogen arc". Two tungsten electrodes were set into brass nozzles attached to tubes connected with a hydrogen tank. A stream of hydrogen was passed through these nozzles and ignited. The arc was then struck between the electrodes and played over a pile of boric acid crystals supported on a porcelain stand. A fine brown powder resulted from this treatment of the boric acid. This powder was digested in c.p. hydrochloric acid for two or three days filtered and dried. It was then packed along a tungsten filament in Pyrex tubes and the tungsten was heated to a white heat electrically. A beautifully crystalline black coarse powder was the result of this treatment.

The next step was to work out a method of chemical analysis to test the purity of the product. As no funds were available in the Laboratory, Mr. Frankel dropped the work at this stage and sought more remunerative employment.

(2) Barium and Strontium.

Experiments leading to the production and x-ray analysis of metallic barium and strontium in which Mr. D.S. Stevens collaborated were commenced in the Autumn of 1926. It was proposed to produce and purify these metals by a method similar to that used by Danner, induction heating being used to distil the metal in a vacuum.

The theory and practice of induction heating were worked up from the literature and a 5 K.W. induction heater was designed and built in the Crystallographic Laboratory. This apparatus provides enough power to fuse sand into a rod of silica half inch in diameter in less than six minutes.

The Laboratory hopes to be able to continue experiments with this apparatus in the near future.

B. Production of Single Crystals of the Metals and Elements.

(1). Selenium and Tellurium.

Experiments to redetermine the crystal structure of selenium and tellurium using single crystals in which Mr. Sparks collaborated were started in the Spring of 1927. It was proposed to grow single crystals by the method of Bridgman (Proc. Amer. Acad. Sci. 60, 305, (1925)). Mr. Sparks was forced to drop this work on account of lack of funds.

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C. Atomic Lattices and Atomic Dimensions.

(1). The Atomic Lattices and the Atomic Dimensions of the Elements Crystallizing in the Cubic and Hexagonal Systems.

The concept of a spherical atom used by W.L. Bragg and W.P. Davey to compute the radii of atomic spheres of influence from the x-ray data of crystal structure, have been specialized and the cubic atoms proposed by G.N. Lewis and extended by Irving Langmuir have been extended to simple polyhedrons inscribable in spheres. Using these simple types of atom models it was shown how they can be built up into the various observed types of cubic and hexagonal lattices.

The fine structure of the atomic lattices of the face-centered cubic lattices, Type I and Type II, the diamond type of cubic lattice, the graphite of hexagonal lattice, the close-packed hexagonal lattice and the body centered cubic lattices Type I and Type II have been worked out in detail.

From these structures, simple geometrical relations connecting the radii of the atoms and the lattice constants have been found. From these relations the radii of the atoms crystallizing in these forms have been computed.

A reprint of this paper which was published in the Proceedings of the National Academy of Sciences will be found at the end of this part of the Bulletin.

It is proposed to extend this work to other types of more complicated lattices as soon as time is available.

(1). The Atomic lattices and the Atomic Dimensions of the Elements
Crystallizing in the Cubic and Hexagonal Systems.

The concept of a spherical atom used by W.L. Bragg and W.P. Davy to compare the radii of atomic spheres of influence from the x-ray data of crystal structures, have been specialized and the cubic atoms proposed by G.N. Lewis and extended by Irving Langmuir have been extended to simple polyhedrons inscribable in spheres. Using these simple types of atom models it was shown how they can be built up into the various observed types of cubic and hexagonal lattices. The three structures of the atomic lattices of the face-centered cubic lattices, Type I and Type II, the diamond type of cubic lattice, the graphite of hexagonal lattice, the close-packed hexagonal lattice and the body centered cubic lattice Type I and Type II have been worked out in detail.

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III. Inorganic Crystals.

A. Ionic Lattices and the Structure of Anhydrous Compounds.

- (1). The Determination of the Space Group of the Sulphates of Potassium, Rubidium and Caesium.

This investigation was started in the Autumn of 1926 by Professor Frank P. Goeder. Orthorhombic crystals of these salts were grown from solution and their space group determined by the method of Laue spots. An account of this investigation was accepted by the Department of Physics of the University of Chicago as fulfilling the thesis requirement for a candidate for the Degree of Doctor of Philosophy. A short account of this work has been published in the Proceedings of the National Academy of Sciences and a reprint of this paper will be found at the end of this part of this Bulletin.

Prof. Goeder also obtained excellent Laue photographs from crystals of ammonium sulphate in the Crystallographic Laboratory and expects to extend his work to these as well as to the determination of the crystals structures of these compounds towards which the space group determination is the first step.

- (2). The Determination of the Space Group of Potassium Nitrate Crystals.

This investigation was started in the Crystallographic Laboratory by Eugene O'Connell, Department of Physics, University of Notre Dame in 1926. Crystals of potassium nitrate have been grown from solution and reflection and Laue photographs have been taken and measured. The interpretation of these photographs is still in progress.

- (3) The Determination of the Space Group of Silver Nitrate Crystals.

This investigation is being carried on by Mr. Albert J. Weiss of Cape Girardeau, Missouri. Silver nitrate crystals have been grown by him, sections made and mounted and sent on to the Crystallographic Laboratory to be photographed.

IV. Organic Crystals.

The organic substances or carbon compounds as they are sometimes called are naturally divided into two main classes (1) the aliphatic compounds which contain open chains of carbon atoms and which can be derived from ethane and (2) the cyclic compounds which have the carbon atoms arranged in a closed ring. The most important of these rings of carbon atoms is the benzene ring which is composed of six carbon atoms. The substances derived from it are called aromatic compounds most dyes and explosives belong to this class. These two compounds - ethane and benzene - are thus key substances and the determination of their correct structure is fundamental for the working out of the structures of organic crystals. No other problem in the structure of matter has received so much attention or has formed the basis of so many investigations as the problem of the structure of the benzene ring.

The most striking and important contributions of the Crystallographic Laboratory to date has been in the solution of the structure of these two substances - ethane and benzene. Not only has the complete structure of the ethane molecule been determined and verified but its lattice structure has been completely worked out. The results of this work are published in two papers. (1) The structure and dimensions of the ethane molecule and (2) The lattice structure of ethane which have appeared in the Proceedings of the National Academy of Sciences, reprints of which will be found at the end of this part of the Bulletin.

In addition to this work, the structure of the benzene ring has been solved and a scale model presented. Isomerism, unsaturation and the non-occurrence of optically active derivatives are all accounted for by this model and for the first time we have a definite quantitative basis on which to interpret the x-ray data obtained from organic crystals of aromatic compounds. A short account of this work entitled "The Structure and Dimensions of the Benzene Ring" has been published in the Proceedings of the National Academy of Sciences and a reprint of this paper will be found at the end of this part of this Bulletin.

4. The Immediate Development Program of the Crystallographic Laboratory.

As can be easily seen from a perusal of the previous sections of this Bulletin, the Crystallographic Laboratory is at present adequately endowed with laboratory space and apparatus. What it lacks is a sufficient budget for Fellowships and Assistantships.

In regard to funds for these purposes, they can be underwritten in one of two ways, (1) by permanent endowment the interest on which is expended and (2) by current contributions which are expended when available which are given for the encouragement of fundamental investigation in the field of crystal structure by individuals or corporations interested in this field. At the present time, modern physics is moving so rapidly and the kind and character of the investigations into its fundamental problems are in such a state of flux that it seems better to finance research programs at the beginning in these newer fields by current contributions rather than by permanent endowment. Furthermore, we firmly believe that in this age a close relation between fundamental research in pure science and the technical development of scientific discoveries is for the best interest of both sorts of investigation. Every year sees an ever growing demand in industry for men thoroughly trained in these modern methods of investigation. And while there can be no doubt that the training and education of such men is one of the primary objects of a university, nevertheless investigation into the fundamental phenomena underlying these applications is of equal importance. Industrial problems and the problems of pure science are based on the same phenomena and are solved by the same methods. They differ only in their objectives. The place to apply x-ray methods of crystal analysis to the problems of plant control is obviously at the plant, the place to develop the industrial applications of the discoveries in crystal structure is in the industrial laboratories located at the works not at university laboratories.

To further this necessary and essential cooperation between pure science and industry, the Crystallographic Laboratory of the University of Chicago offers the opportunity for the establishment of the following types of Research Fellowships.

(1) The Establishment of Two Research Fellowships in Crystal Structure.

These Fellowships to be called "The (Name of Donor) Research Fellowship in Crystal Structure" and they shall pay a minimum of 2000 dollars per year for a period of two years and they can be renewed in two year terms at the pleasure of the donor. These Fellowships are intended for mature investigators who have a Ph.D. degree or training equivalent to it and who desire to continue or take up research in crystal structure. For these Fellowships applicants with industrial experience are preferred. These Fellows are to be selected from those who apply for them by a committee composed of the President or Vice-President of the University of Chicago, the Donor or a representative designated by him, the Chairman of the Department of Physics of the University of Chicago and the permanent staff of the Crystallographic Laboratory. The holders of these Fellowships are expected to publish a report of their investigations before the expiration of their appointments. All contributions made by them shall be headed

Contribution No. - of the Crystallographic Laboratory
Department of Physics, University of Chicago.

(Title of Paper).

By (Name of Fellow), The (Name of Donor Research Fellow in Crystal Structure.

(2) The Establishment of Three Research Assistantships in Crystal Structure.

These Research Assistantships to be called "The (Name of Donor) Research Assistantship in Crystal Structure" and shall pay 1000 dollars peryear for a period of two years. They are intended for graduate students doing thesis work for a higher degree in Physics at the Department of Physics of the University of Chicago, the said work being done in the Crystallographic Laboratory. Due acknowledgement of the grant of this assistantship shall be incorporated in the thesis or published articles by the appointee. Applicants for these Assistantships shall be selected from those who apply by a Committee composed of the Chairmen of the Department of Physics of the UNiversity of Chicago and the permanent staff of the Crystallographic Laboratory.

It is intended that each Research Fellow shall work in close cooperation with the permanent staff of the Crystallographic Laboratory along some definite fundamental problem of crystal structure. The three Research Assistantships are to be distributed among the Research Fellows and the permanent staff of the Crystall^ographic Laboratory and shall work in close cooperation with them. Any other graduate students desiring to work in the Crystallographic Laboratory shall be distributed similarly.

(2) The Establishment of Three Research Assistantships in Crystal Structure.

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It is intended that each Research Fellow shall work in close cooperation with the permanent staff of the Crystallographic Laboratory along some definite fundamental problem of crystal structure. The three Research Assistantships are to be distributed among the Research Fellow and Research Assistant staff of the Crystallographic Laboratory and shall work in close cooperation with them. Any other graduate students desiring to work in the Crystallographic Laboratory shall be distributed similarly.

Amounts needed for

7 file
Crystal

Crystallographic Laboratory

I

2 Research fellowships

@ \$2000 per yr for 2 yrs

\$4000 tot for each year

\$8000 " " 2 yrs

8000

II

3 Research assistantships

@ 1000 per yr for 2 yrs

\$3000 tot for each yr

\$6000 " " 2 yrs

6000

III Cost of printing 1000 copies of

\$850 \$1000

Bulletin No I of the
Crystallographic Laboratory

This bulletin will cover

1 Description of the work in progress and
outlined for the Crystallographic Lab

2 Bibliography since beginning of
this branch of sci in 1913 - ^{of great} ^{value to workers in}

3 Reprint of scientific contributions of
Lab to date - ^{of great val to workers in} ^{this field}

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BULLETIN No. 1. 1926-1927.

The Crystallographic Laboratory, Department of physics, University of Chicago.

Henry Gordon Gale, Chairman.

Jared Kirtland Morse, Research Associate.

1. Introduction.

The Crystallographic Laboratory was first made available for students of Chemistry, Geology, Physics and others interested in the structure of crystals in the Summer Quarter of 1926. At this time also, a series of lectures in the theory and practice of x-ray crystal analysis were given, in order to provide a background for experimental investigation in the Laboratory. The attendance at these lectures was highly gratifying as between forty and forty-five graduate students registered for or visited the course. Following these lectures in the autumn, several pieces of investigation were started. Since this time productive work has actively gone on in this Laboratory and more adequate space and apparatus have been obtained. At present, the Crystallographic Laboratory is seriously handicapped by lack of funds for salaries and fellowships. The purpose of this Bulletin is to give an account not only of the scope of the present work of the Laboratory but also to outline its development program and follow this with a bibliography of the field of Crystal Structure and its applications in research and industry in order that the work and aims of the Crystallographic Laboratory may become better known and receive the support to which it is entitled.

This Bulletin is divided into two parts. Part I. is a brief account of the work and program of the Crystallographic Laboratory. The facilities offered by the Laboratory are first described, the scope of the problems outlined and a tentative program of development presented. Reprints of the scientific contributions of the Laboratory which have been published to date will form the fifth and closing section of this part of the Bulletin. The second part is a Bibliography covering the whole field and brings out clearly the importance of this new branch of Physics in both research and industry.

This new field of investigation — the x-ray analysis of crystals — is one of the most fascinating of the developments of modern Physics. Its method of attack on the problem of the structure of matter was first developed in 1913 one year before the outbreak of the Great War. Since that time its rise has been rapid. In spite of the large amount of work which has already been accomplished in this field the amount of work remaining to be done is enormous. In general the importance of this field of work has been better recognized in Great Britain and on the Continent than in the United States. Although American physicists such as A.W.Hull, Ancel St. John, W.P.Davey, L.W.McKeehan and R.W.G.Wyckoff have done much of the pioneer work. In England the Royal Institution is entirely devoted to crystal analysis and on the Continent especially in Germany there are a number of Institutes devoted to the study of crystals. There is no reason why the United States should lag behind in organized investigation in this field and the University of Chicago in virtue not only of its geographical location but also in respect to the opportunities for cooperative research which it offers is the logical place for this new development.

2. The Facilities Offered by the Crystallographic Laboratory.

(a) Laboratory Space.

The Crystallographic Laboratory has, at present, space available for three full time investigators in addition to the regular staff. There is a large light laboratory on the second floor of the Ryerson Physical Laboratory equipped for x-ray work. The majority of the x-ray diffraction apparatus is concentrated in this laboratory and is so designed that it can be continuously operated all night without attention. This leaves the day-time free for the preparation of crystal sections, the construction of new apparatus, the development, measurement and interpretation of photographs and obviates any injury to the investigators either from x-ray burns or the more insidious and little known injurious physiological effects produce by continuous exposure to secondary x-rays which tend to produce anaemia. In addition to this laboratory there is a combined constant temperature and dark room in the basement for growing crystals and photographic work. In addition and adjoining the large laboratory is a private laboratory for the staff consisting of two rooms. One an office and goniometer and balance room and the other a combination dark room and research laboratory for work with long x-rays.

(b) Equipment.

The Crystallographic Laboratory has at present

(1). A universal x-ray spectrometer for obtaining diffraction photographs by the methods of the rotating crystal, Laue spots and the powder method of Debye and Scherrer. It is operated with air-cooled Coolidge tubes of tungsten and molybdenum and was built in the Ryerson Physical Laboratory.

(2). A universal type Muller x-ray spectrometer built by Hilger and Co of London and operated with a Scheerer tube for long wave length investigations with the radiations from iron and copper.

(3). An x-ray diffraction apparatus for use with powders by the method of Siemens-St. John operated with a water cooled molybdenum tube. This apparatus is especially well adapted for the investigation of industrial problems such as plant control in the heat and mechanical treatment of materials and qualitative x-ray analysis of samples.

(4). A General Electric x-ray diffraction apparatus for the investigation of powdered materials and metals is on order and delivery is promised for December 1927.

(5). Funds are also available for the purchase of a high grade two circle goniometer which will be ordered whenever investigations requiring it are ready to be put under way.

(c). Lectures and Laboratory Instruction.

Two series of lectures are presented twice each every other year at the Laboratory and laboratory instruction in the technique of the x-ray analysis of crystals is offered in the Autumn, Winter and Summer Quarters of each year. The first of these courses is an introduction to the general field of Molecular Physics and the Structure of Matter and the second takes up in detail the theory and practice of Crystal Analysis. It is planned to supplement this last course by a third series of lectures on the Structure of Crystals in which the results of crystal analysis will be outlined and critically discussed as soon as circumstances will permit. The following short outlines of the main headings of these two courses gives an idea of the ground covered in these lectures.

Facilities Offered by the Crystallographic Laboratory

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(b) Equipment.

- The Crystallographic Laboratory has at present:
- (1) A universal x-ray spectrometer for obtaining diffraction photographs by the method of the rotating crystal, Debye spots and the powder method of Debye and Scherrer. It is equipped with air-cooled Coolidge tubes of tungsten and molybdenum and runs with the Rorer Physical Laboratory.
 - (2) A universal type Miller x-ray spectrometer built by Hilger and Co. of London and equipped with a Scherrer tube for long wave length investigation with the radiation from iron and copper.
 - (3) An x-ray diffraction apparatus for use with powder by the method of Bragg and Bragg. This apparatus is a water cooled molybdenum tube. This apparatus is especially well adapted for the investigation of industrial problems such as phase control in the heat and mechanical treatment of materials and qualitative x-ray analysis of samples.
 - (4) A General Electric x-ray diffraction apparatus for the investigation of powdered materials and metals is on order and delivery is promised for December, 1937.
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(1) Molecular Physics and the Structure of Matter.

- I. Introduction.
- II. The Meaning of Science.
- III. The History of Science.
- IV. Kinetic Theory of Gases - The Equation of State - Pressure in a Gas - Specific Heats.
- V. The Theory of Probability - The Method of Least Squares and Their Application to Molecular Problems.
- VI. The Viscosity of Gases and the Effective Diameter on Collision of Molecules.
- VII. The Dynamics of Charged Particles.
- VIII. Introduction to the Quantum Theory.
- IX. Crystal Structure and the Size of Atoms, Ions and Molecules.

(2) X-Ray Crystal Analysis.

- I. Introduction to Crystallography.
Definitions, Elements of Symmetry, Indices of Crystal Faces, Crystal Systems and Classes.
- II. The Geometrical Theory of Crystal Structure.
Space Lattices Point Groups, Space Groups.
- III. Introduction to X-Rays.
Theory of the Crystal Grating, Determination of the Lattice Constant of Sodium Chloride, Relative Determination of X-Ray Wavelengths, Compton's Absolute Determination of X-Ray Wavelengths, Design of X-Ray Tubes, Filters Effects of X-Rays on the Photographic Plate.
- IV. The Determination of Crystal Structure by Reflection from Single Crystals.
- V. The Powder Method of X-Ray Analysis.
- VI. The Determination of Crystal Structure from Laue Photographs.
- VII. Methods of Growing Crystals.
- VIII. Applications of X-Ray Crystal Analysis to Various Problems.

Both these series of lectures are given four days a week, three days being devoted to lectures and the fourth to a general discussion of the ground covered.

(3). Laboratory Instruction in Crystal Analysis.

This course is designed as an introductory course to research in crystal structure and it follows the lecture course in the X-Ray Analysis of Crystals. No definite hours in the laboratory are assigned and not more than four applicants are accepted for any one term. The student first redetermines the structure of a known simple crystal (cubic or hexagonal) by the reflection method and the method of Laue spots. In this way he gains first hand knowledge of growing crystals, identifying faces, cutting sections and taking and interpreting diffraction photographs. In some cases the structure which he obtains by these two methods he checks by means of powder photographs. The results of this work is incorporated in a typewritten report in the form of a scientific paper. At the completion of this work he is ready to take up original investigations of one of the simpler of the many problems in this field.

(1) Molecular Physics and the Structure of Matter

- I. Introduction.
- II. The Meaning of Science.
- III. The History of Science.
- IV. Kinetic Theory of Gases - The Equation of State - Pressure in a Gas - Specific Heats.
- V. The Theory of Probability - The Method of Least Squares and Their Application to Molecular Problems.
- VI. The Kinematics of Gases and the Effective Diameter on Collision of Molecules.
- VII. The Dynamics of Charged Particles.
- VIII. Introduction to the Quantum Theory.
- IX. Crystal Structure and the Size of Atoms, Ions and Molecules.

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- I. Introduction to Crystallography.
Crystals, Elements of Symmetry, Indices of Crystal Faces, Crystal Systems and Classes.
- II. The Geometrical Theory of Crystal Structure.
Space Lattices, Point Groups, Space Groups.
- III. Introduction to X-Rays.
Theory of the Crystal Grating, Determination of the Lattice Constant of Solids, Relative Determination of X-Ray Wavelengths, Bragg's Law, Absolute Determination of X-Ray Wavelengths, Design of X-Ray Tubes, Filters, Effects of X-Rays on the Photo-graphic Plate.
- IV. The Determination of Crystal Structure by Reflection from Single Crystals.
I. The Powder Method of X-Ray Analysis.
- V. The Determination of Crystal Structure from Lens Photographs.
- VI. Methods of Growing Crystals.
- VII. Applications of X-Ray Crystal Analysis to Various Problems.

Both these series of lectures are given four days a week, three days being devoted to lectures and the fourth to a general discussion of the ground covered.

(3) Laboratory Instruction in Crystal Analysis

This course is designed as an introductory course to research in crystal structure and it follows the lecture course in the X-Ray Analysis of Crystals. The laboratory work in the laboratory are assigned and not more than four applications are assigned in any one year. The student first determines the structure of a known single crystal (cubic or hexagonal) by the reflection method and the method of least squares. In this way he gains first hand knowledge of growing crystals, identifying faces, cutting sections and taking and interpreting diffraction photographs. In some cases the structures which he obtains by these methods he checks by means of powder photographs. The results of this work is transmitted in a typewritten report in the form of a scientific paper. At the completion of this work he is ready to take up original investigations of one of the subjects of the many problems in this field.

3. Program of Investigation of the Crystallographic Laboratory.

The field of Crystal Structure can be conveniently divided into the following sections.

I. Technique.

- A. Rotating Single Crystal Methods.
- B. Powder Methods of Crystal Analysis.
- C. Method of Laue Spots.
- D. X-Ray Goniometry.

II. The Crystal Structure of the Elements.

- A. The Space Lattices of the Elements.
- B. The Production of Single Crystals of the Metals and Elements.
- C. Atomic Structure and Dimensions.
- D. The Effect of Mechanical and Heat Treatment on Metals.
- E. The Structure of Alloys and Intermetallic Compounds.
- F. The Reflection of Electrified Particles from Crystals.

III. Inorganic Crystals.

- A. Ionic Lattices and the Structure of Anhydrous Compounds.
- B. The Growing of Single Crystals from Solutions.
- C. Allotropy.
- D. Mixed Crystals.
- E. Valence.
- F. Ionic Dimensions.
- G. The Crystal Structure of Hydrates.
- H. The Structure of Colloids.

IV. Organic Crystals.

- A. The Determination of the Molecular Lattices of Aliphatic Compounds.
- B. Molecular Structure.
- C. Optical Activity and the Structure of Optically active Compounds.
- D. The Structure of the Benzene Ring.
- E. The Determination of the Molecular Lattices of Aromatic Compounds.

Work is now being carried on in the Crystallographic Laboratory in each one of the main branches of the field outlined above and already fundamental contributions have been published in the majority of these sections. A brief account of the work done to date is herewith presented and reprints of the papers already published will be found at the end of this part of the Bulletin.

Program of Investigation of the Crystallographic Laboratory

The field of Crystal Structure can be conveniently divided into the following sections.

I. Techniques

- A. Rotating Single Crystal Methods.
- B. Powder Methods of Crystal Analysis.
- C. Method of Low Angle X-rays.
- D. X-ray Spectrometry.

II. The Crystal Structure of the Elements

- A. The Space Lattices of the Elements.
- B. The Production of Single Crystals of the Metals and Elements.
- C. Atomic Structures and Dimensions.
- D. The Effect of Mechanical and Heat Treatment on Metals.
- E. The Structure of Alloys and Intermetallic Compounds.
- F. The Refinement of Refined Structures from Crystals.

III. Inorganic Crystals

- A. Ionic Lattices and the Structure of Anhydrous Compounds.
- B. The Grouping of Single Crystals from Solutions.
- C. Allotropy.
- D. Mixed Crystals.
- E. Solenes.
- F. Ionic Displacements.
- G. The Crystal Structure of Hydrates.
- H. The Structure of Colloids.

IV. Organic Crystals

- A. The Determination of the Molecular Lattices of Aliphatic Compounds.
- B. Molecular Structure.
- C. Optical Activity and the Structure of Optically Active Compounds.
- D. The Structure of the Benzene Ring.
- E. The Determination of the Molecular Lattices of Aromatic Compounds.

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I. Technique.

(1). The 'Doughnut' Filament Transformer.

An extremely cheap, efficient and easy to construct type of air insulated transformer for heating filaments kept at high potentials has been developed in the Crystallographic Laboratory to take the place of the expensive and unsatisfactory commercial oil immersed, filament transformers now on the market. The core of these 'Dough-nut' transformers consists of 25 pounds of soft annealed "stove pipe" wire wound in a torus whose inside diameter is approximately 14". This is covered with friction tape and wound not too closely with No. 18. cotton covered copper wire. This forms the primary. The secondary consists of another torus of the same size as the primary and the same inside diameter made of No. 8 rubber covered copper wire, the total resistance of this secondary being equal to the total resistance of the filament circuit of the X-ray tube to be used. These two coils, the primary and the secondary are mounted so that their equatorial planes are mutually perpendicular and so that the primary passes through the center of the secondary. These simple transformers will stand any amount of rough treatment without burning out and are in every way satisfactory. They are now in use through out the Ryerson Physical Laboratory.

(2) A Mould for Casting Cylinders of Fine Powders.

In powder analysis by the method of Debye and Scherrer, it has been usual to employ small tubes of special glass, celluloid or collodion to keep the powder in place while the exposure is in progress. These containers when of glass increase the exposure time and when made of materials containing carbon scatter the x-rays and cause considerable general blackening on the photographic plate. To obviate these difficulties, a method of casting these powders into cylinders approximately 0.075 cm. in diameter and 1.5 cm. in length in place in the center of the Debye camera has been worked out in the Crystallographic Laboratory. Figure One shows a cross section of the mould used. A little shellac is used to make the powder base marked (1) in the figure tacky so that the foot of the cylinder will adhere to it. The mould (2) is then screwed down tight and filled from the top with the fine powder care being taken to prevent too much pressure which would cause the crystalline particles to orient themselves. When the mould is full the plunger (3) is set firmly with a set screw (4). The mould is then raised by means of the nut (5) on the thread (6). The plunger is then carefully removed and the whole mould taken off from the brass base leaving the powder cylinder without any container standing vertically in the center of the camera.

(3). A Grinding Goniometer.

In the reflection method and especially in the method of Laue spots, thin plane crystal sections are required cut parallel to a given plane having simple indices. It often happens that the planes required do not occur naturally on the crystals grown. The accurate cutting of these sections and the grinding of them to the required thickness by hand is a difficult and tedious job. A grinding goniometer of suitable design reduces the time and increases the accuracy considerably. Such an apparatus was designed by Mr. W. King Hubbert in the Crystallographic Laboratory in the Spring of 1927 and its construction was well along by the beginning of the Summer. Unfortunately Mr. Hubbert's funds gave out and he was forced to go into industrial work to earn sufficient money on which to live while he continues his investigations of which this instrument is a preliminary part. He expects to be able to continue his work in 1928. This case is typical of the spirit of most of the men interested in this field and illustrates the need of Fellowships to enable such men to carry on their work.

II. The Crystal Structures of the Elements.

A. The Space Lattices of the Elements.

(1). Boron.

In the Summer of 1926, preliminary experiments in which Prof. W.P. Jessie, Of Lehigh University collaborated were made by the method of Debye and Scherrer on powdered boron. Boron crystals were obtained from Eimer and Amend, these were powdered in an agate mortar and an attempt was made to cast them in the mould described above but without success as the powdered boron was so hard that it abraded the brass lining of the mould and could not be removed. Fine collodion cylinders were next prepared, filled with the boron powder and exposed to the radiation from a molybdenum tube. A diffraction pattern was obtained in this way on which six diffraction rings were easily discernable. As the boron used in these experiments was known to be somewhat impure, it was decided to attempt to prepare pure metallic boron in the Laboratory.

In the Winter of 1927 an attempt was made to prepare chemically pure boron. Mr. Frankel collaborated in these experiments. The method employed was to reduce chemically pure boric acid to metallic boron by means of an "atomic hydrogen arc". Two tungsten electrodes were set into brass nozzles attached to tubes connected with a hydrogen tank. A stream of hydrogen was passed through these nozzles and ignited. The arc was then struck between the electrodes and played over a pile of boric acid crystals supported on a porcelain stand. A fine brown powder resulted from this treatment of the boric acid. This powder was digested in c.p. hydrochloric acid for two or three days filtered and dried. It was then packed along a tungsten filament in Pyrex tubes and the tungsten was heated to a white heat electrically. A beautifully crystalline black coarse powder was the result of this treatment.

The next step was to work out a method of chemical analysis to test the purity of the product. As no funds were available in the Laboratory, Mr. Frankel dropped the work at this stage and sought more remunerative employment.

(2) Barium and Strontium.

Experiments leading to the production and x-ray analysis of metallic barium and strontium in which Mr. D.S. Stevens collaborated were commenced in the Autumn of 1926. It was proposed to produce and purify these metals by a method similar to that used by Danner induction heating being used to distil the metal in a vacuum.

The theory and practice of induction heating were worked up from the literature and a 5 K.W. induction heater was designed and built in the Crystallographic Laboratory. This apparatus provides enough power to fuse sand into a rod of silica half inch in diameter in less than six minutes.

The Laboratory hopes to be able to continue experiments with this apparatus in the near future.

B. Production of Single Crystals of the Metals and Elements.

(1). Selenium and Tellurium.

Experiments to redetermine the crystal structure of selenium and tellurium using single crystals in which Mr. Sparks collaborated were started in the Spring of 1927. It was proposed to grow single crystals by the method of Bridgman (Proc. Amer. Acad. Sci. 60, 305, (1925)). Mr. Sparks was forced to drop this work on account of lack of funds.

(1) Boron

In the summer of 1936, preliminary experiments in which Prof. E. S. Ruedemann, of Lehigh University, collaborated were made by the method of Debye and Scherrer on powdered boron. Boron crystals were obtained from Elmer and Asahi. These were powdered in an agate mortar and an attempt was made to cast them in the mold described above but without success as the powdered boron was so hard that it abraded the brass lining of the mold and could not be removed. Thin sections of crystals were next prepared, filled with the boron powder and exposed to the radiation from a molybdenum tube. A diffraction pattern was obtained in this way on which six diffraction rings were easily discernible. As the boron used in these experiments was known to be somewhat impure, it was decided to attempt to prepare pure metallic boron in the laboratory.

In the winter of 1937, attempts were made to prepare chemically pure boron. It was found that boron could be prepared in these experiments. The method employed was to reduce chemically pure boric acid to metallic boron by means of an "active hydrogen" gas. Two tungsten electrodes were set into glass tubes sealed at both ends and connected with a hydrogen tank. A stream of hydrogen was passed through these tubes and ignited. The end was then struck between the electrodes and played over a pile of boric acid crystals supported on a porcelain stand. A fine brown powder resulted from this treatment of the boric acid. This powder was digested in a 2% hydrochloric acid for two or three days filtered and dried. It was then packed along a tapered filament in Pyrex tubes and the tungsten was heated to a white heat electrically. A beautifully crystalline black coarse powder was the result of this treatment.

The next step was to work out a method of chemical analysis to test the purity of the product. As no funds were available in the laboratory, Dr. Ruedemann proposed the work at this stage and sought more transmissive equipment.

(2) Selenium and Tellurium

Experiments leading to the production and x-ray analysis of metallic selenium and tellurium in which Mr. E. S. Ruedemann collaborated were commenced in the autumn of 1936. It was proposed to produce and purify these metals by a method similar to that used by Gurney induction heating being used to distill the metal in a vacuum.

The theory and practice of induction heating were worked up from the literature and a 5 K.W. induction heater was designed and built in the Crystallographic Laboratory. This apparatus provides enough power to heat and melt a rod of metal half inch in diameter in less than six minutes. The laboratory hopes to be able to continue experiments with this apparatus in the near future.

B. Production of Single Crystals of the Metals and Elements

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C. Atomic Lattices and Atomic Dimensions.

(1). The Atomic Lattices and the Atomic Dimensions of the Elements Crystallizing in the Cubic and Hexagonal Systems.

The concept of a spherical atom used by W.L. Bragg and W.P. Davey to compute the radii of atomic spheres of influence from the x-ray data of crystal structure, have been specialized and the cubic atoms proposed by G.N. Lewis and extended by Irving Langmuir have been extended to simple polyhedrons inscribable in spheres. Using these simple types of atom models it was shown how they can be built up into the various observed types of cubic and hexagonal lattices.

The fine structure of the atomic lattices of the face-centered cubic lattices, Type I and Type II, the diamond type of cubic lattice, the graphite of hexagonal lattice, the close-packed hexagonal lattice and the body centered cubic lattices Type I and Type II have been worked out in detail.

From these structures, simple geometrical relations connecting the radii of the atoms and the lattice constants have been found. From these relations the radii of the atoms crystallizing in these forms have been computed.

A reprint of this paper which was published in the Proceedings of the National Academy of Sciences will be found at the end of this part of the Bulletin.

It is proposed to extend this work to other types of more complicated lattices as soon as time is available.



Sum of Equations of the 5th Degree
from the circle

2. Atomic Lattices and Atomic Dimensions.

(1) The Atomic Lattices and the Atomic Dimensions of the Elements
Crystallizing in the Cubic and Hexagonal Systems.

The concept of a space lattice as used by W.L. Bragg and W.P. Barrett to compute the radii of atomic spheres of influence from the x-ray data of crystal structures, have been generalized and the cubic atoms proposed by G.K. Laves and extended by Irving Langmuir have been extended to atomic polyhedra in interstitial spaces. Using these simple types of atom models it was shown that they can be built up into the various observed types of cubic and hexagonal lattices. The fine structure of the atomic lattices of the face-centered cubic lattices, Type I and Type II, the diamond type of cubic lattices, the graphite of hexagonal lattices, the close-packed hexagonal lattice and the body centered cubic lattice Type I and Type II have been worked out in detail.

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III. Inorganic Crystals.

A. Ionic Lattices and the Structure of Anhydrous Compounds.

- (1). The Determination of the Space Group of the Sulphates of Potassium, Rubidium and Caesium.

This investigation was started in the Autumn of 1926 by Professor Frank P. Goeder. Orthorhombic crystals of these salts were grown from solution and their space group determined by the method of Laue spots. An account of this investigation was accepted by the Department of Physics of the University of Chicago as fulfilling the thesis requirement for a candidate for the Degree of Doctor of Philosophy. A short account of this work has been published in the Proceedings of the National Academy of Sciences and a reprint of this paper will be found at the end of this part of this Bulletin.

Prof. Goeder also obtained excellent Laue photographs from crystals of ammonium sulphate in the Crystallographic Laboratory and expects to extend his work to these as well as to the determination of the crystals structures of these compounds towards which the space group determination is the first step.

- (2). The Determination of the Space Group of Potassium Nitrate Crystals.

This investigation was started in the Crystallographic Laboratory by Eugene O'Connell, Department of Physics, University of Notre Dame in 1926. Crystals of potassium nitrate have been grown from solution and reflection and Laue photographs have been taken and measured. The interpretation of these photographs is still in progress.

- (3) The Determination of the Space Group of Silver Nitrate Crystals.

This investigation is being carried on by Mr. Albert J. Weiss of Cape Girardeau, Missouri. Silver nitrate crystals have been grown by him, sections made and mounted and sent on to the Crystallographic Laboratory to be photographed.

III. Isomeric Crystals

A. Some Isomers and the Structure of Anhydrous Compounds.

(1) The Determination of the Space Group of the Sulphates of Potassium, Rubidium and Caesium.

This investigation was started in the autumn of 1926 by Professor Ernest R. Gorter, Orthopedic crystals of these salts were grown from solution and their space group determined by the method of Laue spots. An account of this investigation was accepted by the Department of Physics of the University of Chicago as fulfilling the thesis requirement for a candidate for the degree of Doctor of Philosophy. A short account of this work has been published in the Proceedings of the National Academy of Sciences and a reprint of this paper will be found at the end of this part of this Bulletin.

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This investigation is being carried on by Dr. Albert J. Weiss of Gage Chemical Company. Silver nitrate crystals have been given by him, sections made and mounted and sent on to the Crystallographic Laboratory to be photographed.

IV. Organic Crystals.

The organic substances or carbon compounds as they are sometimes called are naturally divided into two main classes (1) the aliphatic compounds which contain open chains of carbon atoms and which can be derived from ethane and (2) the cyclic compounds which have the carbon atoms arranged in a closed ring. The most important of these rings of carbon atoms is the benzene ring which is composed of six carbon atoms. The substances derived from it are called aromatic compounds most dyes and explosives belong to this class. These two compounds - ethane and benzene - are thus key substances and the determination of their correct structure is fundamental for the working out of the structures of organic crystals. No other problem in the structure of matter has received so much attention or has formed the basis of so many investigations as the problem of the structure of the benzene ring.

The most striking and important contributions of the Crystallographic Laboratory to date has been in the solution of the structure of these two substances - ethane and benzene. Not only has the complete structure of the ethane molecule been determined and verified but its lattice structure has been completely worked out. The results of this work are published in two papers. (1) The structure and dimensions of the ethane molecule and (2) The lattice structure of ethane which have appeared in the Proceedings of the National Academy of Sciences, reprints of which will be found at the end of this part of the Bulletin.

In addition to this work, the structure of the benzene ring has been solved and a scale model presented. Isomerism, unsaturation and the non-occurrence of optically active derivatives are all accounted for by this model and for the first time we have a definite quantitative basis on which to interpret the x-ray data obtained from organic crystals of aromatic compounds. A short account of this work entitled "The Structure and Dimensions of the Benzene Ring" has been published in the Proceedings of the National Academy of Sciences and a reprint of this paper will be found at the end of this part of this Bulletin.

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4. The Immediate Development Program of the Crystallographic Laboratory.

As can be easily seen from a perusal of the previous sections of this Bulletin, the Crystallographic Laboratory is at present adequately endowed with laboratory space and apparatus. What it lacks is a sufficient budget for Fellowships and Assistantships.

In regard to funds for these purposes, they can be underwritten in one of two ways, (1) by permanent endowment the interest on which is expended and (2) by current contributions which are expended when available which are given for the encouragement of fundamental investigation in the field of crystal structure by individuals or corporations interested in this field. At the present time, modern physics is moving so rapidly and the kind and character of the investigations into its fundamental problems are in such a state of flux that it seems better to finance research programs at the beginning in these newer fields by current contributions rather than by permanent endowment. Furthermore, we firmly believe that in this age a close relation between fundamental research in pure science and the technical development of scientific discoveries is for the best interest of both sorts of investigation. Every year sees an ever growing demand in industry for men thoroughly trained in these modern methods of investigation. And while there can be no doubt that the training and education of such men is one of the primary objects of a university, nevertheless investigation into the fundamental phenomena underlying these applications is of equal importance. Industrial problems and the problems of pure science are based on the same phenomena and are solved by the same methods. They differ only in their objectives. The place to apply x-ray methods of crystal analysis to the problems of plant control is obviously at the plant, the place to develop the industrial applications of the discoveries in crystal structure is in the industrial laboratories located at the works not at university laboratories.

To further this necessary and essential cooperation between pure science and industry, the Crystallographic Laboratory of the University of Chicago offers the opportunity for the establishment of the following types of Research Fellowships.

(1) The Establishment of Two Research Fellowships in Crystal Structure.

These Fellowships to be called "The (Name of Donor) Research Fellowship in Crystal Structure" and they shall pay a minimum of 2000 dollars per year for a period of two years and they can be renewed in two year terms at the pleasure of the donor. These Fellowships are intended for mature investigators who have a Ph.D. degree or training equivalent to it and who desire to continue or take up research in crystal structure. For these Fellowships applicants with industrial experience are preferred. These Fellows are to be selected from those who apply for them by a committee composed of the President or Vice-President of the University of Chicago, the Donor or a representative designated by him, the Chairman of the Department of Physics of the University of Chicago and the permanent staff of the Crystallographic Laboratory. The holders of these Fellowships are expected to publish a report of their investigations before the expiration of their appointments. All contributions made by them shall be headed

Contribution No. - of the Crystallographic Laboratory
Department of Physics, University of Chicago.

(Title of Paper).

By (Name of Fellow), The (Name of Donor Research Fellow in Crystal Structure.

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Contribution No. - of the Crystallographic Laboratory

Department of Physics, University of Chicago.

(Title of paper).

By (Name of Fellow), The (Name of Donor) Research Fellow in Crystal Structure.

(2) The Establishment of Three Research Assistantships in Crystal Structure.

These Research Assistantships to be called "The (Name of Donor) Research Assistantship in Crystal Structure" and shall pay 1000 dollars peryear for a period of two years. They are intended for graduate students doing thesis work for a higher degree in Physics at the Department of Physics of the University of Chicago, the said work being done in the Crystallographic Laboratory. Due acknowledgement of the grant of this assistantship shall be incorporated in the thesis or published articles by the appointee. Applicants for these Assistantships shall be selected from those who apply by a Committee composed of the Chairmen of the Department of Physics of the University of Chicago and the permanent staff of the Crystallographic Laboratory.

It is intended that each Research Fellow shall work in close cooperation with the permanent staff of the Crystallographic Laboratory along some definite fundamental problem of crystal structure. The three Research Assistantships are to be distributed among the Research Fellows and the permanent staff of the Crystallographic Laboratory and shall work in close cooperation with them. Any other graduate students desiring to work in the Crystallographic Laboratory shall be distributed similarly.

1. The Establishment of Three Research Assistantships in Crystal Structures.

Three Research Assistantships to be called "The (Name of Donor) Research Assistantship in Crystal Structures" and shall pay 1000 dollars per year for a period of two years. They are intended for graduate students doing thesis work for a degree in Physics at the Department of Physics of the University of Chicago. The said work being done in the Crystallographic Laboratory. The appointment of the grant of this assistantship shall be determined by the Committee on Graduate Studies of the University of Chicago and the permanent staff of the Crystallographic Laboratory.

It is intended that each Research Fellow shall work in close cooperation with the permanent staff of the Crystallographic Laboratory along some definite line of research in crystal structures. The three Research Assistantships are to be held by the Research Fellow and the permanent staff of the Crystallographic Laboratory. The Research Fellow shall be in close cooperation with the permanent staff of the Crystallographic Laboratory.

9200
2900
11900
5500

X-ray crystal analysis

- ① Used to test metals
 - ② ^{& single} Long crystal filaments more durable than filaments made of several crystals stuck together
 - ③ ^{Can steel wire resist} Diamonds in dies last longer if placed in right plane of crystals
-

X-ray anal of crystals is important bec

- ① It gives facts on the structure of matter
- ② It gives a method for testing metals which is quicker and surer than chemical analysis
- ③ It has many bearings on industry such as the method of making filaments the method of setting diamonds in machine dies.

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