NATIONAL ACADEMY OF SCIENCES

HENRY NORRIS RUSSELL

1877—1957

A Biographical Memoir by

HARLOW SHAPLEY

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BY HARLOW SHAPLEY

HENRY NORRIS RUSSELL was born on October 25, 1877, in Oyster Bay, New York, the son of a Presbyterian minister. His education was acquired principally at home until the age of twelve, and then at the Princeton Preparatory School and Princeton University; from the latter he was graduated in 1897 with the highest standing ever attained by a Princeton undergraduate. Throughout all of his mature life, as a member of the Princeton faculty, he lived at 79 Alexander Street, but spent many summers on the New England coast or in travel.

Russell was awarded in due course all the formal distinctions that America's leading astronomer merited. He was made a foreign associate of the Royal Societies of London, Edinburgh, and Belgium; Correspondent of the French Academy of Sciences, and Associate of the Royal Astronomical Society of London. His honorary degrees came from Dartmouth, Louvain, Harvard, Chicago, Michoacan (Mexico); his medals and prizes from the Royal Astronomical Society of London, the French Academy (Lalande and Janssen), National Academy of Sciences (Draper), Astronomical Society of the Pacific (Bruce), American Academy of Arts and Sciences (Rumford), Franklin Institute (Franklin), and the American Philosophical Society (John L. Lewis prize). He was the first Henry Norris Russell Lecturer of the American Astronomical Society.

In Russell's brief autobiographical statement for the National

Academy of Sciences two paragraphs report on his natural interest in mathematics and on his early education:

"It may be relevant to record that a strong interest in mathematics appears to 'run in the family.' My maternal grandmother won a mathematical prize on her graduation in 1840 from Rutgers Female Institute in New York (the first institution in that city for the higher education of women). My mother was easily first in a 'ladies class' in mathematics given by professors of the University of Edinburgh about 1868. I was awarded a fellowship in mathematics on my graduation from Princeton. My children, though none of them have followed careers in the mathematical sciences, have all enjoyed their courses in mathematics and done well in them with no great effort.

"I was always interested in astronomy. (I recall my parents showing me the transit of Venus in 1882, when I was five years old.) Specialized interest in it was aroused mainly by C. A. Young of Princeton—a great teacher as well as a great astronomer. My first independent contribution dealt with the atmosphere of Venus."

My address to the American Astronomical Society in May, 1957, on Russell's scientific work follows:

In Colonel Stratton's obituary of Henry Norris Russell in *Nature* for March 16, 1957, appears this concluding evaluation: "A man of overflowing energy, never sparing himself in his own work or in assisting the researches of others, he was the most eminent and versatile theoretical astrophysicist in the United States if not in the world."

When I cast back in my memory (before I examine the full bibliography), I pick out the following as Russell's most outstanding contributions:

1. The color magnitude diagram.
2. Eclipsing binary theory and calculations.
3. Spectrum analysis, laboratory and stellar.
4. The masses of stars, including analysis of visual double stars.
5. Popularization of astronomy at a high level.

This last refers to the famous textbook with Dugan and Stewart, to some general lectures, and especially to the monthly contribution, over forty years, to the *Scientific American*—a survey of astronomical problems and progress much like the current series by Otto Struve in *Sky and Telescope.*

In the foregoing five fields Russell did indeed do outstanding work, but picking up the list of about 200 technical papers, I see that I have left out at least five fields that should not have been overlooked:

6. Solar and stellar composition and constitution (for example, the "Russell mixture" so much used in cooking up atmospheric models).

7. The origin of the planets and comets.

8. Characteristics of planetary atmospheres.

9. The contacts of religion with science, and vice versa—and

10. Perhaps the most important of all, general consulting on all astronomical and spectroscopic problems.

Colonel Stratton is right about the unequaled versatility of Russell, who has written modestly of himself that as a boy he was rather acutely studious, "somewhat preferring mathematical studies, and with *no marked scholastic dislikes.*" Going much further, all of us would agree that the word *genius* more rightly applies to him than to any other American astronomer of these or earlier times. And as a genius he was at times pretty hard going for many of us followers who think and talk slowly and raggedly. As one of his first graduate students I quickly learned to use monosyllables—"Yes, No, Yes? So? How's that?" and "Ummmm." That drawling monosyllable "Ummmm" conceals more careful ignorance than any other in the Queen's English. I doubt if I fooled him. We would walk on the Princeton campus, he waving his cane to shoo the inconsequential students off the walks—he calculating and scintillating—I listening, guessing, wondering, trying to de-confuse myself. You may remember that I claim to be the original Russell Mixture.

Of the ten major fields of Russell's interest and activity, I shall choose only three or four for comment. First the happy assignment

and acceptance of being America's wide-ranging astronomical consultant.

Beginning in the early 1920s Russell was officially a visiting research associate at the Mount Wilson Observatory. When I was shipped East to Harvard, so the rumor goes, they were happy that the released dollars (there were not very many, I assure you) permitted the bringing of Russell to Pasadena. It was indeed a clever bargain arranged by Mr. Hale.

From Russell's long association with Mount Wilson came many scientific contributions—largely spectroscopic. Some were inspired by his association with Walter S. Adams, A. S. King, and H. D. Babcock. Later he was made an official research associate of the Harvard Observatory. And he also regularly visited the Lick and Lowell Observatories, the National Bureau of Standards, and other research groups. One year he was Morrison Research Associate on Mount Hamilton. The assistance he gave everywhere was immense—criticisms, hunches, and much computational labor. He liked to mess around with numbers.

In the few paragraphs that he has written about himself for the records of the National Academy of Sciences, he says, "I have always enjoyed detailed numerical work," and such computational work has been used freely in all his investigations. Professor Dugan once remarked, "Russell will spend much more time hunting for ingenious short cuts than would be required to take the long cut."

Russell's informal role over three decades as National Astronomical Consultant was supplemented formally by joint authorships of scientific publications. His first collaborator was Arthur R. Hinks at Cambridge, England, where, in his early post-doctorate days, he measured trigonometric parallaxes of stars without too much success.

In 1912 began our joint work on the orbital theory and practice of eclipsing binary stars; and at the same time began the collaboration of Harvard, Yale, and Princeton on the positions of the moon determined photographically. "Harvard makes photographs, Princeton

makes measures, and Yale thinks" was alleged to be the arrangement. The collaborators were E. C. Pickering, E. W. Brown, Russell, and a philanthropist (George Russell Agassiz) who paid for the many girl-hours.

I have made a list of subsequent joint authorships—about twenty-five in number. Here are some of the names: Adams, Joy, Stewart, Saunders, Dugan, Karl Compton, Boyce, Menzel, Bowen, Shenstone, Meggers, Arthur King, Robert King, Mrs. Gaposchkin, and, most frequently collaborating, Charlotte Moore (Sitterly). Many other contributions could well have carried his name as joint author, but such credits did not interest Russell. He was casual about credits to himself, but intense about anybody's scientific discoveries.

While still a Princeton graduate student, Russell published two papers that pointed directly to two of his future life-long interests. The first was "The Atmosphere of Venus," published in 1899 in the then young *Astrophysical Journal*. It makes good reading today; it shows a distinct maturity. Later that year appeared his paper "The Densities of Variable Stars of the Algol Type." Many of his subsequent papers deal with eclipsing stars, and also a large number with planetary atmospheres.

Other early scientific papers (1897–1900) touched celestial mechanics, e.g., "The Great Inequality of Eros and the Earth." That was the time of considerable excitement over the highly eccentric orbit of the newly discovered asteroid. Russell's last published paper, by the way, was encouraged by Mrs. Nail and me a couple of years ago. We tempted him, after he had thought his effective work was completed, by sending him light curves of some eclipsing stars in the Magellanic Clouds. (It is well, we argued, to be sure that the gravitational laws are the same in those mixed up galaxies as in our own; it is important also to see if the stars are similar in general respects.) Russell's contribution (this last one) was printed, just a week before his death, in the second volume of Dr. Beer's *Vistas*.

Most of Russell's last decade of work dealt with eclipsing star

orbital theory. He devoted much time to the work of J. E. Merrill and Z. Kopal.

Beginning in the middle of the 1920s he turned his guns on the mysteries of radiation. He devoted more of his time to spectrum analysis, a subject on which he has left an indelible impression. With Saunders, Charlotte Moore Sitterly, Meggers, Lang, Bowen, and others, he brought order out of chaos among the arc and spark spectra of the elements.

From 1925 to 1930 his activity produced twenty papers on line spectra. Some of them were classics, such as "A Calibration of Rowland's Scale of Intensities for Solar Lines," "The Arc and Spark Spectra of Titanium" (130 pages in the *Astrophysical Journal*), and, with F. A. Saunders, "The Spectrum of Ionized Calcium." This last introduced the famous Russell-Saunders coupling in complex spectra.

That interval of five years yielded also the Russell-Dugan-Stewart two-volume textbook, which reoriented and essentially revolutionized astronomical teaching and astronomical textbook writing in America. Also at that time he gave the Terry lectures at Yale which resulted in the book *Fate and Freedom*. In this same pentad of activity appeared (with Mrs. Sitterly as joint author) the important catalogue of the dynamical parallaxes of 1,777 double stars.

The 1930s were also furiously active and scientifically enjoyable—the work being more spectroscopic than astronomical. Much more could be said of Russell's work on laboratory and stellar spectra, but I should devote a little time to some miscellaneous half-forgotten enterprises.

There was the tricky analysis in 1921 of radioactive data which led to his fixing the upper limit to the age of the earth's crust. He starts with the observation that if the whole crust had been originally composed of uranium it would have decayed to the present terrestrial abundance in 17 half-periods, or 8.5×10^{10} years. "But this assumption," he remarked, "would lead to the absurd conclusion that the

crust must now be composed entirely of the products of the radioactive disintegration of the original uranium." He considers the lead situation, and the contribution of thorium, and eventually concludes, "indeed it might be safe to say that the age of the crust is between two and eight thousand millions of years." That was thirty-five years ago, and much has since been done in age measurement by techniques then unknown. But he had it right. Now we would probably say between four and six thousand million years.

The Terry lectures in Yale in 1927 resulted as remarked above in the small book *Fate and Freedom*. The three chapters are: "Fate and Freedom," "God and Man," "Body and Soul." I recommend the book to those of you who are wondering about human fate, as doomed by the stars and solaced by the comforts of religion.

On page 132 of *Fate and Freedom* I find a rather satisfactory personal definition of that evasive concept "soul." Russell says: "By soul I mean here the personality, the conscious individual who understands, feels, remembers, responds to us." Soul equals personality. I rather like that. But Russell states, "When the body dies the soul vanishes utterly." I do not agree with that view. He is inconsistent. I always intended to point out to him the obvious error. For the personality (therefore soul) survives. His personality, in a sense, is here at the present time and will continue to survive. But he and I didn't get to argue such things—eclipsing stars and the iron multiplets always got in the way. Perhaps it is just as well.

Russell's proper field of science was astronomy and spectroscopy, but on the side he was interested in poetry, geology, archaeology, botany, and travel. He knew the Princeton countryside and the deserts of the Southwest; he knew the North Cape and the Nile Valley with its monuments.

In those early Princeton days, I, as an uncouth Missourian, was accepted with some reservations, but gradually I improved, and at last became aware of my arrival when Russell very privately told me a deep secret; that is, he told me just where in the woods four miles

north of Princeton I could find the rare and precious fringed gentian. I had indeed made good!

To report a little further on his miscellaneous scholarly interests, I note in the bibliography the following: "Determinism and Responsibility," "A Planetary Date for Chaucer's Troilus," "The Borders of the Humanities." During the First World War there appeared a paper "On the Navigation of Airplanes."

Of more professional concern were the following contributions: "Dark Nebulae," "On Majorana's Theory of Gravitation," "Model Stars," "On the Origin of Periodic Comets," "The Probable Diameter of Stars," "The Solar Spectrum and the Earth's Crust," "The Masses of the Stars" (an important monograph), and the highly useful "List of Ultimate and Penultimate Lines of Astrophysical Interest." We do not have space here to explore these contributions, but conclude by coming back to the planets, where Russell began his scientific thinking.

His book entitled *The Solar System and Its Origin* has been a guide and inspiration to the many recent workers in this important field. Research and speculations have gone far since Russell's University of Virginia lectures. Later contributions have come from Alfven, ter Haar, Kuiper, Lyttleton, Urey, von Weizsaecker, Whipple, and others, but Russell's contribution of more than twenty years ago was distinctly the guiding pioneer work, both as a survey of the then current thought and as a rich source of suggestion.

In restrospect we note that Russell never seemed to interest himself in Milky Way structure, or in the many problems of the star clusters and galaxies, possibly because I talked too fast about them and he had little chance to contribute. Also he did not get deeply into the field of meteors. But he appeared to cover about all other astronomical fields in lively interest and many of them in original research. And he enjoyed his researches immensely, especially those where he must calculate the consequences of this and that. One of my clearest pictures of him shows his eager thoughtful gaze at the ceiling, or

the horizon, with a 10-inch slide rule in his hands. He carried the logarithm tables in his phenomenal memory.

A few weeks ago I stood alone, with bared head, in the front yard at 79 Alexander Street, when his body was taken into the study from which I had so often come out inspired and determined; and I thought: "His interval out of infinite time is nobly concluded; it is now our continuing responsibility to pay interest on the investment he made in us."

KEY TO ABBREVIATIONS

A. J. = Astronomical Journal
Annals, H. C. O. = Annals of Harvard College Observatory
Annals, N. Y. Acad. Sci. = Annals of the New York Academy of Sciences
Ap. J. = Astrophysical Journal
B. A. A. J. = British Astronomical Association Journal
Bull. Amer. Math. Soc. = Bulletin of the American Mathematical Society
Carnegie Inst. Wash. Publ. = Carnegie Institute of Washington Publications
H. C. O. Bull. = Harvard College Observatory Bulletin
H. C. O. Circ. = Circulars of the Harvard College Observatory
Harv. Reprint = Reprints from the Harvard College Observatory
Helwan Publ. = Publications of the Helwan Observatory
J. Franklin Inst. = Journal of the Franklin Institute
J. Opt. Soc. Amer. = Journal of the Optical Society of America
J. R. A. S. Can. = Journal of the Royal Astronomical Society of Canada
J. Res. Nat. Bur. St. = Journal of Research of the National Bureau of Standards
Lick Obs. Cont. = Contributions from Lick Observatory
M. N. = Monthly Notices of the Royal Astronomical Society
Mt. Wilson Cont. = Mount Wilson Contributions
N. R. C. Bull. = National Research Council Bulletin
Nat. Hist. = Natural History
Obs. = Observatory
P. A. = *Popular Astronomy*
P. A. S. P. = Publications of the Astronomical Society of the Pacific
P. U. Obs. Cont. = Princeton University Observatory Contributions
Phys. Rev. = Physical Review
Pr. Alumni Weekly = Princeton Alumni Weekly
Pr. Univ. Bull = Princeton University Bulletin
Proc. Amer. Phil. Soc. = Proceedings of the American Philosophical Society.
Proc. N. A. S. = Proceedings of the National Academy of Sciences
Proc. R. Soc. = Proceedings of the Royal Society of London
Publ. A. A. S. = Publications of the American Astronomical Society
Publ. Modern Lang. Assn. Amer. = Publications of the Modern Language Association of America
Sci. Am. = Scientific American
Sci. Mo. = Scientific Monthly
Sci. Pa. B. S. = Scientific Papers of the Bureau of Standards
Tech. Rev. = Technology Review
Trans. Amer. Phil. Soc. = Transactions of the American Philosophical Society
Trans. I. A. U. = Transactions of the International Astronomical Union

BIBLIOGRAPHY

NOTE: The monthly articles appearing in *The Scientific American* from March 31, 1900, through August, 1943, have not been included in this Bibliography.

1898

A New Graphical Method of Determining the Elements of a Double-Star Orbit. A. J., 19:9–10; P. A. 6(3):149–55.
Elements of the Planet DQ. A. J., 19:147.

1899

Elements and Ephemeris of Eros. A. J., 20:8.
Ephemeris of Eros. A. J., 20:31.
The Atmosphere of Venus. Ap. J., 9:284–99.
The Densities of Variable Stars of the Algol Type. Ap. J., 10:315.
Measures of the Diameter of Jupiter. A. J., 20:77.
Elements of Eros. A. J., 20:134.

1900

With Charles A. Young. Princeton Eclipse Expedition Number. Part V: "Report of Mr. Russell." Pr. Univ. Bull., 11:84–85.
The Great Inequality of Eros and the Earth. A. J., 21:24.
The General Perturbations of the Major Axis of Eros, by the Action of Mars. A. J., 21:25–28.

1902

An Improved Method of Calculating the Orbit of a Spectroscopic Binary. Ap. J., 15:252–60.
Shadows Cast by Starlight. P. A., 10:242–46.

1905

With Arthur Hinks. Determinations of Stellar Parallax from Photographs Made at the Cambridge Observatory. Introductory Paper. M. N., 65:775–87.
The Parallax of Lalande 21185 and γ Virginis from Photographs Taken at the Cambridge Observatory. M. N., 65:787–800.
On the Light Variations of Asteroids and Satellites. Ap. J., 24:1–18.

1906

With A. R. Hinks. The Parallax of 8 Stars from Photographs Taken at the Cambridge Observatory. M. N., 67:132–35.

1907

Note on Paper on the Probable Distance of Orion. P. A., 15:444; Science, n.s., 25:564.

With Zaccheus Daniel. Venus a Luminous Ring. P. A., 15:516; Ap. J., 26:69–70.

1908

On the Illumination of the Dark Side of Saturn's Rings. Ap. J., 27:230–33.

1909

Elements and Ephemeris of Daniel's Comet (1909e). A. J., 26:46.

1910

On the Origin of Binary Stars. Ap. J., 31:185–207.

Determinations of Stellar Parallax. A. J., 26:147–59.

Mass Ratios in the Systems of Krueger 60 and Castor. Ap. J., 32:363–71.

Some Hints on the Order of Stellar Evolution (Abstract, A.A.S.). Science, n.s., 32:883–84.

1911

Determinations of Stellar Parallax. Carnegie Inst. Wash., Publ. 147.

Position of the Moon Determined Photographically. Annals, H.C.O., 72(1):1–14.

A Study of Visual Binary Stars (Abstract, A.A.S.). Science, n.s., 34: 523–25.

Photographic Determination of the Position of the Moon (Abstract, A.A.S.). Science, n.s., 34:534–36.

1912

Notes on the Determination of the Elements of Algol Variables (Abstract). P. A., 20:199; Science, n.s., 35:708.

On the Determination of the Orbital Elements of Eclipsing Variable Stars. Ap. J., 35:315–40; 36:54–74.

The Eclipsing Variables W Centauri and W Ursae Majoris (Abstract). P. A., 20:200; Science, n.s., 35:708.

Elements of the Eclipsing Variables W Delphini, W Ursae Majoris, and W Crucis. Ap. J., 36:133–55.

Comments on the Parallaxes of the 61 Cygni Group (A. J. 629). A. J., 27:95–96.

Stars Probably Belonging to the 61 Cygni Group Discovered by Mr. Benjamin Boss (A. J. 629). A. J., 27:96.

With Harlow Shapley. On Darkening at the Limb in Eclipsing Variables. Ap. J., 36:239–54; 385–408.

1913

On the Graphical Representation of Eclipsing Variables (Abstract, A.A.S.). Science, 37:30.

On the Luminous Efficiency and Colour-Index of a Black Body at Different Temperatures (Abstract, A.A.S.). Science, n.s., 37:646.

Notes on the Real Brightness of Variable Stars (Abstract, A.A.S.). Science, n.s., 37:651–52.

On the Reduction of Polar Trail Plates. M. N., 73:735–42.

"Giant" and "Dwarf" Stars (Address Given at the Meeting of the National Academy of Sciences, June 13, 1913). Obs., 36:324–29.

Relations between the Spectra and Other Characteristics of the Stars (Address Delivered before Joint Meeting of the Astronomical and Astrophysical Society and Section A of the A.A.A.S. at Atlanta, Georgia, Dec. 30, 1913). P. A., 22:275–94; 331–51; Proc. Amer. Phil. Soc., 51:569–79; Publ. A.A.S., 16th Meeting; Science, n.s., 35:793–94.

1914

The Probable Order of Stellar Evolution. Obs., 37:165–75.

Relations between the Spectra and Other Characteristics of the Stars (Address before Astronomical and Astrophysical Society, Atlanta, Georgia, Dec. 30, 1913). P. A., 22, Nos. 5–6; (with a few additions) Nature, 93:pt. I, pp. 227–30; pt. II, pp. 252–58; pt. III, pp. 281–86.

Solar Spectrum and the Earth's Crust. Science, n.s., 39:791–94.

With Harlow Shapley. Elements of the Eclipsing Variable Stars Z Draconis and RT Persei. Ap. J., 39:405–27.

A Short Method for Determining the Orbit of a Spectroscopic Binary. Ap. J., 40:282–93.

With Harlow Shapley. On the Distribution of Eclipsing Variable Stars in Space. Ap. J., 40:417–34.

1915

Princeton's Work in Astronomy. The Princeton Pictorial Review, 3: 319–22.

With Mary Fowler. Photographic Determinations of the Position of the Moon. Annals, H.C.O., 76:127–60.

1916

The Stellar Magnitudes of the Sun, Moon, and Planets. Ap. J., 43:103–29.
On the Albedo of the Planets and Their Satellites. Ap. J., 43:173–96; Proc. N. A. S., 2:74.
The Photographic Brightness of the Full Moon. Ap. J., 44:128–30.
Note on the Parallax of a Star in Ophiuchus. H. C. O. Bull., p. 617.
Percival Lowell and His Work. The Outlook, 114:781.

1917

The Minimum Radiation Visually Perceptible. Ap. J., 45:60–64.
Preliminary Parallax of Barnard's Star of Large Proper Motion. A. J., 30:73–75.
The Orbit of Epsilon Equulei. A. J., 30:123–26.
Orbit of Krueger 60. A. J., 30:131–36.
With Mary Fowler, Martha C. Borton, and Ernestine Fuller. Photographic Determinations of the Position of the Moon. Annals H. C. O., 80:191–219.
With Mary Fowler and Martha C. Borton. Comparison of Visual and Photographic Observations of Eclipsing Variables. Ap. J., 45:306–47.
Masses of the Stars. P. A., 25:666.

1919

Variable Stars (Address of Vice President and Retiring Chairman of Section A of the A.A.A.S., Baltimore, Dec. 27, 1928). Science, n.s., 49:127–39.
Orbit of σ Ursae Majoris, 21306 (Abstract). P. A., 27:97–98.
Edward Charles Pickering. Science, n.s., 49:151–55.
On the Navigation of Airplanes. P. A. S. P., 31:129–49.
On the Sources of Stellar Energy. P. A. S. P., 31:205–11.
Some Problems of Sidereal Astronomy. Proc. N. A. S., 5:391–416; P. A., 28:212–24; 264–75.

1920

With H. L. Cooke. A Proposed Method for Carrying Triangulation across Wide Gaps. Science, n.s., 51:211–13.
Modifying Our Ideas of Nature: The Einstein Theory of Relativity. Princeton Lectures No. 2, Princeton, N. J., May 1, 1920; Smithsonian Report for 1921, pp. 197–212.
Note on Strömberg's Method of Determining Mean Absolute Magnitudes. P. A. S. P., 32:243–44.

On the Origin of Periodic Comets. A. J., 33:49–61.

The Probable Diameters of the Stars. P. A. S. P., 32:307–17; J. R. A. S. Can., 15:83; Abstract, P. A., 29:30–31.

Note on the Sobral Eclipse Photographs. M. N., 81:154–64.

Planetary Families of Comets (Report given at the 19th A.A.S. Meeting). Nature, 105:467.

Masses of Stars (Report given at the 21st Meeting, A.A.S., 1920). Nature, 105:500.

The Determination of the Position of the Moon by Photography. P. A. S. P., 32:105–11.

1921

Radiation Pressure and Celestial Motions. Ap. J., 53:1–12.

Stellar Evolution (Address Given before British Astronomical Association, Feb. 23, 1921). B. A. A. J., 31:178–82; P. A., 29:541–45.

A Superior Limit to the Age of the Earth's Crust. Proc. R. Soc., A, 99: 84–86.

An Obstacle to the Use of Artificial Horizons at Sea. M. N., 81:417–20.

Rubidium in the Sun. P. A. S. P., 33:202–4.

Observations of the Aurora at the Lowell Observatory, May 14, 1921. Science, n.s., 54:183–87.

On the Accuracy with Which Mean Parallaxes Can be Determined from Parallactic and Peculiar Motions. Ap. J., 54:140–45; Mt. Wilson Cont., 215.

Note on Cooling by Expansion in Sun-spots. Ap. J., 54:293–95; Mt. Wilson Cont., 217.

The Properties of Matter as Illustrated by the Stars (Address Delivered in Berkeley, Aug. 5, 1921, before Pacific Division of A. A. A. S.). P. A. S. P., 33:275–90.

1922

On Majorana's Theory of Gravitation. Ap. J., 54:334–46; Mt. Wilson Cont., 216.

With David L. Webster. Note on the Masses of the Stars. M. N., 82:181–82.

On the Orbital Eccentricity of Binary Stars of Very Long Period (Abstract). P. A., 30:167–68; Nature, 109:560.

The Theory of Ionization and the Sun-Spot Spectrum. Ap. J., 55:119–44; Mt. Wilson Cont., 225.

Recent Advances in Stellar Astronomy. I. The Light of the Stars. II. The Sizes and Masses of Stars. III. The Constitution and Evolution of the

Stars (Three Lectures at Rice Institute, Jan. 26–28, 1922). Rice Inst. Pamphlet., 9:41–109.

On the Calculation of Masses from Spectroscopic Parallaxes. Ap. J., 55: 238–41; Mt. Wilson Cont., 227.

Notes on Ionization in the Solar Atmosphere. Ap. J., 55:354–59; Mt. Wilson Cont., 236.

With E. W. Brown, Chairman, G. D. Birkhoff, and A. O. Leuschner. Celestial Mechanics (Report of the Committee on Celestial Mechanics of the N. R. C.). N. R. C. Bull., 4:1–22.

Dark Nebulae. Proc. N. A. S., 8:115–18; Nature, 110:81–83.

The New International Symbols for the Constellations. P. A., 30:469–71.

1923

Ionization and Pressure in the Reversing Layers of the Stars (Abstract). P. A., 31:22–24.

Some Results of a Study of Visual Double Stars (Abstract). P. A., 31: 250–51.

With W. S. Adams and A. H. Joy. A Comparison of Spectroscopic and Dynamical Parallaxes. P. A. S. P., 35:189–93.

Singlet Series in the Spark Spectrum of Aluminium. Nature, 113:163.

1924

Ultimate and Penultimate Lines in Spectra (Abstract). P. A., 32:229–30.

Series in the Arc and Spark Spectra of Titanium (Abstract). P. A., 32: 230–31.

With John Q. Stewart. Pressures at the Sun's Surface. (Paper Given before National Academy of Sciences, April, 1923). Ap. J., 59:197–209.

A New Form of the Exclusion Principle in Optical Spectra. Science, n.s., 59:512–13.

With E. W. Brown, Chairman, L. J. Comrie, and W. S. Eichelberger. Report of the Committee on Eclipses, A. A. S. P. A., 32:450–61.

Notes on the Sun-Spot Spectrum (Abstract). P. A., 32:620–21.

With Robert Kilburn Root. A Planetary Date for Chaucer's *Troilus*. Publ. Mod. Lang. Assn. Amer., 39:48–63.

The Application of Modern Physics to Astronomy (A Condensed Report of a Course of Lectures Delivered at the University of Toronto, Feb. 12–29, 1924, by Henry Norris Russell, by H. F. Balmer). J. R. A. S. Can., 18:126–29; 137–64; 201–23; 233–63.

With K. T. Compton. A Possible Explanation of the Behaviour of the Hydrogen Lines in Giant Stars. Nature, 114:86–87.

1925

The Intensities of Lines in Multiplets. Nature, 115:835–36.

The Problem of Stellar Evolution. Nature, 116:209–12.

With F. A. Saunders. New Regularities in the Spectra of the Alkaline Earths. Ap. J., 61:38–69.

The Constitution and Evolution of the Stars (Reprinted from Rice Inst. Pamphlet, 9(2), Apr., 1922. Last of a Series of Three Lectures). Smithsonian Report, 1923, pp. 145–58.

The New Physics and the Stars. Yale Review, 14:463–81.

A List of Ultimate and Penultimate Lines of Astronomical Interest. Ap. J., 61:223–83; Mt. Wilson Cont., 286.

Dispersed Systems in Astronomy. In: J. Alexander's *Colloid Chemistry* (Van Nostrand, 1926), pp. 444–46.

The Intensities of Lines in Multiplets. I. Theory. II. Observed Data. Proc. N. A. S., 11:314–28.

With F. A. Saunders. On the Spectrum of Ionized Calcium (Ca II). Ap. J., 62:1–7.

Note on the Relations between the Mass, Temperature, and Luminosity of a Gaseous Star. M. N., 85:935–39.

1926

With Charlotte E. Moore. On the Winged Lines in the Solar Spectrum. Ap. J., 63:1–12.

Note on Ionization in Giant and Dwarf Stars. H. C. O. Circ., 291.

On the Problem of Stellar Evolution (Abstract). P. A., 34:244–45.

An Outdoor Optical Experiment. Science, n.s., 63:616.

A New Term in the Arc Spectrum of Magnesium. P. A. S. P., 38:236–39.

The Use of Models in an Astronomical Museum. Nat. Hist., 26:399–401.

Multiplets in the Spark Spectrum of Iron. Ap. J., 64:194–203; Mt. Wilson Cont., 318.

1927

Fate and Freedom (Terry Lectures on Religion in the Light of Science and Philosophy Delivered in 1925 at Yale University). New Haven, Conn., Yale Univ. Press.

The Relation of Physics to Astronomy. In: *Physics in Its Relations,* a

symposium by Pupin, Morgan, Whitney, Russell, Millikan, and Saunders, published by Vassar College.

On the Calculation of the Spectroscopic Terms Derived from Equivalent Electrons. Phys. Rev., 29:782–89.

With William F. Meggers. An Analysis of the Arc and Spark Spectra of Scandium (Sc I and Sc II). Sci. Pa. B. S., 22:329–73; Phys. Rev., 29:606A.

With R. J. Lang. On the Spectra of Doubly and Trebly Ionized Titanium (Ti III and Ti IV). Ap. J., 66:13–42; Mt. Wilson Cont., 337.

On the Relations between Period, Luminosity, and Spectrum among Cepheids. Ap. J., 66:122–34; Mt. Wilson Cont., 339.

Series and Ionization Potentials of the Elements of the Iron Group. Ap. J., 66:233–55; Mt. Wilson Cont., 342.

The Arc and Spark Spectra of Titanium. Pt. I. The Spark Spectrum, Ti II; Pt. II. The Arc Spectrum, Ti I. Ap. J., 66:283–328; 347–438; Mt. Wilson Cont., 344/5.

Related Lines in the Spectra of the Elements of the Iron Group. Ap. J., 66:184–216; Mt. Wilson Cont., 341.

With R. S. Dugan and J. Q. Stewart. Astronomy. 2 vols. Boston, Ginn and Co.

1928

On the Spark Spectrum of Oxygen (O II). Phys. Rev., 31:27–33.

With K. T. Compton and J. C. Boyce. The Spark Spectra of Neon and Argon (N. Y. Meeting Physical Society, Feb. 24–25, 1928). Abstract, Phys. Rev., 31:709A.

With K. T. Compton and J. C. Boyce. The Spark Spectrum of Neon. Proc. N. A. S., 14:280–83.

On the Determination of Dynamical Parallaxes. A. J., 38:89–99.

With A. G. Shenstone. A Quick Method of Reducing Prismatic Spectra. J. Opt. Soc. Amer. and R. S. I., 16:298–300.

With W. S. Adams. A New Method of Determining Temperatures and Pressures in Stellar Atmospheres (Abstract). P. A., 36:294–95.

With W. S. Adams and C. E. Moore. A Calibration of Rowland's Scale of Intensities for Solar Lines. Ap. J., 68:1–8; Mt. Wilson Cont., 358; Abstract, P. A., 36:295.

With W. S. Adams. Preliminary Results of a New Method for the Analysis of Stellar Spectra. Ap. J., 68:9–36; Mt. Wilson Cont., 359; Abstract; P. A. S. P., 40:272–73.

On the Advance of Periastron in Eclipsing Binaries. M. N., 88:641–43.

With J. C. Boyce and K. T. Compton. Extreme Ultra-violet Spectrum of Argon Excited by Controlled Electron Impacts. Phys. Rev., 32:179–85.

With Charlotte E. Moore. The Presence of Predicted Iron Lines in the Solar Spectrum and the Terms in the Arc Spectrum of Iron. Ap. J., 68:151–64; Mt. Wilson Cont., 365.

1929

Stellar Evolution. In: *Encyclopaedia Britannica,* 14th ed.

On Meteoric Matter Near the Stars. Ap. J., 69:49–71.

With I. S. Bowen. Is There Argon in the Corona? Ap. J., 69:196–208.

With William F. Meggers. An Analysis of the Arc and Spark Spectra of Yttrium (Yt I and Yt II). J. Res. Nat. Bur. St., 2:733–69; Phys. Rev., 31:1124A. (Washington Meeting of the American Physical Society, Apr. 20, 1928).

Facing the Universe (Editorial). The Outlook, 152:19.

With A. G. Shenstone and L. A. Turner. Report on Notation for Atomic Spectra. Phys. Rev., 33:900–6.

Learning from the Eclipse (Editorial). The Outlook, 152:381.

On the Composition of the Sun's Atmosphere. Ap. J., 70:11–82; Mt. Wilson Cont., 383.

The Arc Spectrum of Nickel (Ni I). Phys. Rev., 34:821–57.

With Charlotte E. Moore. Dynamical Parallaxes of 1777 Double Stars. A. J., 39:165–208.

1930

Life in Time and Space. In: E. V. Cowdry, *Human Biology and Racial Welfare* (New York, Paul B. Hoeber, Inc.), pp. 3–31.

A Note on Zeeman Patterns. Phys. Rev., 36:1590–91.

More about Pluto. Sci. Amer., 143:446–47; J. R. A. S. Can., 25:27–34 (1931).

With R. S. Dugan. Apsidal Motion in Y Cygni and Other Stars. M. N., 91:212–15.

1931

Molecules in the Sun's Atmosphere (Abstract of Paper Given before National Academy of Sciences, April, 1931). Science, n.s., 73:502–3.

With R. d'E. Atkinson. The Stellar Graveyard. Nature, 127:661.

Composite Polytropic Gas Spheres. M. N., 91:739–51.

Meteor Crater. Museum Notes (Museum of Northern Arizona), 4:1–3.

Notes on the Constitution of the Stars. M. N., 91:951–66.

1932

With A. G. Shenstone. Perturbed Series in Line Spectra. Phys. Rev., 39: 415–34.

Mean Ionization in Stellar Atmospheres. Ap. J., 75:337–47; Mt. Wilson Cont., 447.

The Master Key of Science; Revealing the Universe through the Spectroscope (Address Delivered at Massachusetts Institute of Technology, Feb. 25, 1932). Sci. Mo., 34:487–91; Tech. Rev., 34:279; Smithsonian Report (1932), pp. 133–39.

The Composition of the Sun (First Arthur Lecture, under the Auspices of the Smithsonian Institution, Jan. 27, 1932). Smithsonian Report (1931), pp. 199–214.

Note on Milne's Theory of Stellar Structure. M. N., 92:831–36.

With William F. Meggers. An Analysis of Lanthanum Spectra (La I, La II, La III). J. Res. Nat. Bur. St., 9:625–68.

New Planetary Discoveries. Sci. Amer., 147:146–47; J. R. A. S. Can., 26:391–94.

1933

The Constitution of the Stars (First Maiben Lecture before A. A. A. S. at Atlantic City, Dec. 30, 1932). Science, n.s., 77:65–79; J. R. A. S. Can., 27:375–91.

The Composition of the Stars (Halley Lecture, June 1, 1933, at the University of Oxford, Oxford, England). Oxford Univ. Press. 31 pp.

The Attraction of Spheres. Science, n.s., 77:412.

With Charlotte E. Moore. On the Masses of Binary Stars (Abstract). Science, n.s., 77:455.

With Charlotte E. Moore. On the Masses of Giant Stars (Abstract, 49th meeting A. A. S.). P. A. A. S., 7:184–85.

A Rapid Method for Visual Binary Orbits (Paper before R. A. S., London, June 9, 1933). Obs., 56:210–11; M. N., 93:599–602.

Opacity Formulae and Stellar Line Intensities. Ap. J., 78:239–97; Mt. Wilson Cont., 477.

With Donald H. Menzel. The Terrestrial Abundance of the Permanent Gases. Proc. N. A. S., 19:997–1001; Harv. Reprint, 103; Science, n.s., 78:518.

1934

The Atmospheres of the Stars (Medal Day Address, May 16, 1934). J. Franklin Inst., 218:127–42.

Molecules in the Sun and Stars. Ap. J., 79:317–42; Mt. Wilson Cont., 490.
With H. D. Babcock and Charlotte E. Moore. Series Lines of Magnesium in the Solar Spectrum. Phys. Rev., 46:826–27.
The Spectrum and Ionization Potential of Radium. Phys. Rev., 46:989–90.
With A. S. King. The Arc Spectrum of Europium. Phys. Rev., 46:1023.
With J. C. Boyce and A. G. Shenstone. Rydberg Interpolation Table. Depts. of Astronomy and Physics, Princeton University. 20 pp.
Astronomy. In: *American Year Book, 1934,* pp. 652–59.

1935

The Absorption Bands in the Spectra of the Outer Planets (Address Given at Pittsburgh A. A. A. S. Meeting, Dec. 31, 1934). Science, n.s., 81:1–9; J. R. A. S. Can., 29: 51–53.
The Atmospheres of the Planets (Address as Retiring President, A. A. A. S., Dec. 31, 1934, Pittsburgh, Pa.). Science, n.s., 81:1–9; Nature, 135 (Suppl. No. 3406):219–26.
With Cecilia H. Payne-Gaposchkin and D. H. Menzel. The Classification of Stellar Spectra. Ap. J., 81:107–18.
Recent Progress in Astronomy. In: *Encyclopaedia Britannica,* "The World Today," 2:42–45.
With Harold D. Babcock. The Zeeman Effect in the Arc Spectrum of Vanadium. In: *"Pieter Zeeman, 1865–25 Mei-1935,* Verhandelingen op 25 Mei 1935 aangeboden aan Prof. Dr. P. Zeeman (Martinus Nijhoff, 1935), pp. 286–92.
The Analysis of Spectra and Its Applications in Astronomy (George Darwin Lecture, R. A. S., London, June 14, 1935). M. N., 95:610–36.
The Solar System and Its Origin (The Page-Barbour Lectures, University of Virginia, Nov. 13–15, 1934). New York, Macmillan. 139 pp.
The Newer Telescopes. Sci. Amer., 152:294–95; J. R. A. S. Can., 29:231–37.
Astronomy and Astrophysics. In: *The American Year Book, 1935,* pp. 616–21.

1936

With T. Dunham, Jr. and R. Wildt. Planetary Atmospheres (Survey for Council Notes). M. N., 96:376–84.
Note on the Motion of Masses of Gas Seen near Nova Herculis. P. A. S. P., 48:29.
Tables for Intensities of Lines in Multiplets. Ap. J., 83:129–39; Mt. Wilson Cont., 537.

With R. J. Lang, A. S. King, and R. B. King. Recent Progress in the Analysis of Rare-earth Spectra (Abstract for N. A. S. Meeting, April, 1936).

Orbit of the Binary Ref. Cat. 17^h31. A. J., 45:95–96.

With W. F. Meggers. Term Analysis of the First Spectrum of Vanadium (V I). J. Res. Nat. Bur. St., 17:125–92.

The Masses of the Stars (Lecture at Harvard University Tercentenary Conference, Sept. 3, 1936). Ap. J. Monograph, Apr., 1940.

Polytropic Index and Photospheric Conditions. M. N., 97:127–32.

1937

Model stars (First Josiah Willard Gibbs Lecture, New York City, Oct. 31, 1936). Bull. Amer. Math. Soc., 43:49–77.

Astronomy. In: *American Year Book for 1936,* pp. 621–25.

With Robert B. King and R. J. Lang. The Third Spectrum of Corium (Co III). Phys. Rev., 52:456–66.

How Did It All Begin? (Parts of a chapter from Adamson's *The Solar System and Its Origin*). The Sky, 1:12–3.

Ar planetsystemet frukten av en enlevering? (Notes sent to Editor of *Svenska Dagbladet*). Olosta Gator och Aktuella Problem, *Svenska Dagbladet* Naturventen skapliga Enquete (Stockholm, Wahlstrom and Widstrand); pp. 217–20.

1938

Fitting Atmospheres to Stars. M. N., 98:199–202.

The Place of Approximate Methods in Astronomy (Address as Retiring President of the A. A. S., Dec. 30, 1937, at Bloomington, Ind.). Publ. A. A. S., 9:108–14.

With Charlotte E. Moore. A Comparison of Spectroscopic and Trigonometric Parallaxes (Abstract). Publ. A. A. S., 9:133; Mt. Wilson Cont., 589; Ap. J., 87:389–423.

Emission Lines in Astronomical Spectra. Trans. I. A. U., 6:427–29.

Het nieuwe mars-mysterie (Translation of *The New Martian Puzzle* in Scientific American, Sept., 1937, by Dr. J. C. Proost-Thoden van Velsen.). Hemel en Dampkring, 36y:241–45.

With R. S. Dugan and J. Q. Stewart. Supplement to volume II of *Astronomy* (a revision of Young's *Manual of Astronomy*), New York, Ginn and Co.

1939

A Natural Scientist Evaluates Intellectual Freedom (Address on Lincoln's Birthday, Feb. 12, 1939, in Alexander Hall). Pr. Alumni Weekly, 39: 479–81.

Notes on Ellipticity in Eclipsing Binaries (Abstract). Publ. A. A. S., 9:227; Sky, 3:3.

Notes on Ellipticity in Eclipsing Binaries. Ap. J., 90:641–74.

Stellar Energy (Lecture at Franklin Institute, Feb. 17, 1939, Jointly with American Philosophical Society Symposium on Progress of Astrophysics). J. Franklin Inst., 228:143–57; Proc. Amer. Phil. Soc., 81:295–307; J. R. A. S., 33:287–300.

With A. S. King. The Arc Spectrum of Europium. Ap. J., 90:155–203; Mt. Wilson Cont., 611.

1940

Astronomy Department. Pr. Alumni Weekly, 40:318.

With Charlotte E. Moore. The Masses of the Stars with a General Catalogue of Dynamical Parallaxes. Ap. J. Monograph, Apr. 236 pp.

The Time-scale of the Universe (9th James Arthur Lecture, New York University, May 14, 1940). Science, n.s., 92:19–27.

With Robert B. King and Charlotte E. Moore. The Arc Spectrum of Cobalt. Phys. Rev., 58:407–36.

With Charlotte E. Moore. The Systematic and Accidental Errors of Spectroscopic Parallaxes. Ap. J., 92:354–91; Mt. Wilson Cont., 636.

With Charlotte E. Moore. Neutral Barium in the Sun. P. A. S. P., 52: 373–75.

With Charlotte E. Moore. Neutral Barium in the Sun (Abstract, 64th meeting A. A. S., Wellesley, Sept., 1940). Publ. A. A. S., 10:64.

1941

The Distribution of Density within the Stars (Symposium, "The Internal Constitution of the Stars," New York Academy of Sciences, Oct. 20, 1939). Annals N. Y. Acad. Sci., 41:5–12.

Review of *Time and Its Mysteries—Series II* (New York, New York Univ. Press, 1940). Sci. Mo., October, pp. 377–78.

The Cosmical Abundance of the Elements (Address Delivered Sept. 26, 1941 at the Symposium in Connection with the Fiftieth Anniversary Celebration of the University of Chicago). Science, n.s., 94:375–81; (Abstract), Nature, 148:647–49.

With Walter Albertson and Dorothy N. Davis. The Spark Spectrum of Europium, Eu II. Phys. Rev., 60:641–56.

1942

Notes on Eclipsing Variables. Ap. J., 95:345–55.

Spectral Structure and Ionization Potential of Gadolinium I. Ap. J., 96:11–4; Mt. Wilson Cont., 663.

The Present State of the Theory of Stellar Evolution (Inter-American Astrophysical Congress, Puebla, Mexico, Feb. 19, 1942). Sci. Mo., 55: 233–38.

1943

Paramount and Absolute Obligations. Religion in Life, Summer issue.

Determinism and Responsibility (Paper for Conference on Science, Philosophy, and Religion). Science, n.s., 97:249–53.

Physical Characteristics of Stellar Companions of Small Mass. P. A. S. P., 55:79–86.

The Orbit of 70 Ophiuchi. P. A. S. P., 55:104–6.

1944

The Borders of the Humanities. The Sewanee Review, 52:203–9.

Notes on White Dwarfs and Small Companions. A. J., 50:13–17.

Provisional Elements of the Eclipsing Binary V 444 Cygni. Ap. J., 100: 213–18.

With C. E. Moore and D. W. Weeks. The Arc Spectrum of Iron (Fe I). Trans. Amer. Phil. Soc., n.s., 34, pt. II.

1945

With R. S. Dugan and J. Q. Stewart. Astronomy, Vol. I (rev. ed.). New York, Ginn and Co.

Are the Planets Habitable? (A Radio Talk on the New York Philharmonic Symphony Program Sponsored by U. S. Rubber Co. on CBS). Science Illustrated, July/Aug.

Intermediary Elements for Eclipsing Binaries. Ap. J., 102:1–13.

Comments on Captain Whitney's Paper. Ap. J., 102:207.

1946

The Determination of the Elements of Binary Stars. P. A., 54:162–76.

Rectification of the Light-curves of Eclipsing Variables. Ap. J., 104:153–59.

1947

The Ivory Tower and the Ivory Gate (Address Delivered at the Bicentennial Conference, Sept. 25, 1946). In: *Physical Science and Human Values*. Princeton Univ. Press.

America's Role in the Development of Astronomy. Proc. Amer. Phil. Soc., 91:10–16.

Present Needs in the Study of Eclipsing Binaries. Bulletin of the Panel on Orbits of Eclipsing Binaries, No. 6, pp. 1–9; Harvard Circ., 451.

1948

On the Distribution of Absolute Magnitude in Populations I and II. P. A. S. P., 60:202–4.

Preliminary Solutions for Eclipsing Binaries from Accurate Observations. Harv. reprint, 312; Ap. J., 108:53–55.

Configurations of the Low Terms of Ti II. Phys. Rev., 74:689–90.

The Royal Road of Eclipses (First Henry Norris Russell Lecture). Centennial Symposia, Harvard Observatory Monograph, 7:181–209.

Idealized Models and Rectified Light-curves for Eclipsing Variables. Ap. J., 108:388–412; Lick Obs. Cont., Ser. II, 23.

The Penumbral Part of the Reflection Effect in Eclipsing Variables—A Reconnaissance. Harv. Circ., 452:1–8.

The Arc and Spark Spectra of Gadolinium. J. Opt. Soc. Amer., 40:550–75.

1950

Estimation of Ionization Potentials by Comparison with Neighboring Elements. J. Opt. Soc. Amer., 40:618–19.

1952

Introductory Remarks to the Symposium (Symposium on the Hertzsprung-Russell Diagram, Dec. 26–29, 1951). A. J. 57:1–2.

Spectra in the Laboratory and the Stars. Helwan Publ. Cairo, Egypt.

With John Ellsworth Merrill. The Determination of the Elements of Eclipsing Binaries. P. U. Obs. Cont., No. 26.

With Charlotte E. Moore. Binding Energies for Electrons of Different Types. J. Res. Nat. Bur. St., 48:61-67; R. P. 2285, Jan. 1952.

1954

With Charlotte E. Moore. The First Spectrum of Barium, Ba I. J. Res. Nat. Bur. St., 55:299–306; R. P. 26633, Dec. 1955.

Magellanic Clouds XIII. Comparison of Magellanic and Galactic Eclipsing Variables. Proc. Nat. Acad. Sci., 40:549–50.

Eclipsing Variables in the Magellanic Clouds. In: A. Beer, ed., *Vistas in Astronomy* (London, 1957), p. 1177.