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ARTHUR S. KING

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A Biographical Memoir by

ROBERT B. KING

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BY ROBERT B. KING

ARTHUR SCOTT KING was born on January 18, 1876, in Jerseyville, Illinois, and died in Pasadena, California, on April 17, 1957. He was elected to the National Academy of Sciences in 1940. His father, Robert Andrew King, born in Missouri in 1830, was a descendant of Scottish-Irish from Northern Ireland who settled in Virginia in the eighteenth century and moved to Washington County, Missouri, in 1817. Arthur's mother, Miriam Munson King, came from a New England family that had emigrated from Lincolnshire, England, in the seventeenth century. Robert Andrew King studied law and set up a successful practice in Union, Missouri. He also served in the Missouri state legislature. During the Civil War, he moved his family to Jerseyville, Illinois, where he served as circuit judge for southern Illinois, sitting in Jerseyville. Arthur's older brother, Louis, was born in Jerseyville.

Arthur was a rather frail boy and suffered from chronic asthma brought on, his parents believed, by the damp climate of southern Illinois. This was a major reason for the family's move to California in 1883. They purchased a small farm about five miles north of Santa Rosa, at the point where Mark West Creek emerges from the hills into the Santa Rosa plain.

Robert Andrew set up a law office in Santa Rosa, commuting by horse and buggy. The healthy California climate was effective, and Arthur was never again troubled with asthma; in fact, he was remarkably healthy the rest of his long life. Around 1890 the family moved to Fresno, where Arthur's father again set up an active law practice and Arthur attended the public schools. During the latter part of the nineteenth century, the great central valley of California was rapidly becoming the state's agricultural heart and Fresno the metropolis of the southern portion of the valley. A notable event in King's life here, and one that he liked to recall in later years, was a pack trip with a group of Fresno men and boys into the Kings River Canyon. At that time, this was undisturbed wild mountain country, now part of a national park. He attended the Fresno public schools, graduated from Fresno High School in 1895, and was admitted to the University of California (then only one campus) at Berkeley. During his undergraduate years at Berkeley, King became interested in science, especially physics, in which he must have done well because on graduation in 1899, he was admitted to the graduate school in physics.

At the beginning of the twentieth century, spectroscopy was becoming a major field of research in physics. No adequate theory yet existed to explain the lines observed with a spectrograph when elements were heated by flame, arc, or high-voltage spark. However, a great deal of data on measurement of wavelengths and estimated relative intensities of lines appearing in arc and spark spectra were being published. King was intrigued by this, and, fortunately, his research supervisor, Professor Percival Lewis, was interested in spectroscopy. King's first paper, published in the *Astrophysical Journal* in 1901, was concerned with the structure of the cyanogen bands (CN) as was his third paper (with Professor Lewis) in 1902. King's final examination for the Ph.D. degree took place on May 8, 1903. His thesis was titled "The Structure of Arc Spectra and Some Effects of Changes in Physical Conditions." He was awarded his doctorate, the first Ph.D. in physics given by the University of California, which since then has probably produced more Ph.D.s in physics than any other American university.

King was fortunate to receive a Whiting Fellowship for study abroad. The size of the fellowship is not known, but it was sufficient to enable him to spend two years in the physics laboratories of the universities of Bonn and Berlin, then the leaders in spectroscopic research, and to do considerable traveling in Europe as well. The majority of his time was spent in the laboratory of the leading spectroscopist of the time, Professor Heinrich Kayser, at Bonn. Kayser's *Handbuch der Spectroscopy*, continually revised, was the primary source of data on wavelengths, estimated intensities, and identification of the spectral lines of the elements. In Kayser's laboratory King designed and built his first electric furnace for excitation of the spectra of metals. It was clear to him that the furnace provided a new range of controlled excitation fitting with the existing sequence of spectroscopic sources: flames, arc, and spark, between the flame and the arc. His first paper on the electric furnace was published in the *Annalen der Physik* in 1905.

King's primary interests were in the changes in the spectra of the elements produced by different methods and degrees of excitation. At that time, excitation was pretty well limited to the classic arc, spark, and flame sources. Of course, these showed quite different sets of spectral lines, which led to the distinction between spectra of neutral and ionized atoms of the metals. Obviously, a source capable of producing spectra under conditions of thermal equilibrium with controllable temperatures would be highly desirable. King returned to Berkeley as an instructor in physics in 1905.

Two notable events in King's life occurred in 1906: one was a paper he published in the *Annalen der Physik* that described an electric furnace for spectroscopic purposes. This was the forerunner of the King furnace. The other was his marriage to Louise Burnett, the daughter of a Presbyterian minister and a descendent of early New England and New York families. The Kings had two sons, Robert, born in 1908, and Ralph, born in 1911.

In 1907 George E. Hale offered King a position on the staff of the recently established Mt. Wilson Observatory in Southern California. Hale, founder and first director of the observatory, was forming a staff of competent young men who were destined to dominate observational astronomy for many years. Hale was a strong believer in the need for an associated physical laboratory to provide data necessary for interpretation of astronomical observations, especially spectroscopic observations of the sun and stars for which the great telescopes located on Mt. Wilson were designed. Hale's remarkable enthusiasm was shared by the staff. He had the ability to pick good people, not only the scientific staff but the support people as well. He also felt that one of the main objectives of the observatory should be the undertaking of basic and extended research programs seldom undertaken by university researchers at that time because they depended on continued support over a long period of time and significant results were not expected to be forthcoming in a few months. This policy applied to both astronomical and physical laboratory programs. The large endowment (for the time) from the Carnegie Institution of Washington was able to provide continuing support for major projects such as the Mt. Wilson Observatory. At that time there was no National Science Foundation, and financial support of scientific research by the government came largely through private and state-supported universities.

A physical laboratory as part of the observatory was one of Hale's several innovative policies. He had already set up a small laboratory on the mountain that soon proved to be impractical largely due to power limitations. It was also Hale's idea that it would be best for the observatory staff to live in Pasadena rather than on Mt. Wilson. This also has proved to be a wise decision. Consequently, the laboratory was established in Pasadena in conjunction with the shops and offices of the staff. In 1908 Hale published an article in the *Astrophysical Journal* describing a new physical laboratory being constructed for the observatory in Pasadena. At the time it was probably the best-equipped physical laboratory west of Chicago.

In the same issue of the *Astrophysical Journal* containing Hale's article was a paper by King describing a newly designed electric vacuum furnace for spectroscopic observations. This was the furnace that became known as the King furnace. It remained basically unchanged during King's long series of spectroscopic observations extending over almost forty years.

The heating element of the furnace was an accurately machined graphite tube about one-half inch in diameter inside with an eighth-inch wall thickness. The tube was clamped between graphite blocks, which in turn were held tightly in water-cooled metal clamps. The whole assembly was enclosed in a vacuum chamber with quartz windows at each end. Voltages in five volt stages between 5 and 50 volts provided high currents through the tube. The current was controlled by a rheostat, while the observer could continually monitor the temperature inside the tube by means of an optical pyrometer. Temperatures up to 3000°C could be achieved, and almost any solid substance could be melted or vaporized and most of its molecules dissociated. The incandescent vapor, when focused on the slit of a spectrograph, produced emission lines, mainly those of the neutral atom. At high furnace temperatures, the molecular bands of C_2 and CN became prominent. Absorption spectra could be observed by placing a graphite plug in the center of the furnace tube or by focusing the beam of light from a source of continuous spectrum such as a tungsten filament at the center of the heated tube, then onto the slit of the spectrograph. The photographic plate holder was mounted on a horizontal track above floor level.

The Pasadena laboratory was equipped with two large electrograting spectrographs. One had a plane grating in a 30-foot-focus, Litrow-type mounting. The second used a concave grating of 15-feet focus in a Rowland-type mounting. Both were mounted vertically in a pit. This arrangement provided more free floor space and excellent temperature stability. Most of King's work was done with the concave grating spectrograph.

Ever since his European sojourn King had loved to travel. In 1914 he purchased a new Overland touring car, a powerful medium-size four-cylinder automobile, and began to explore the local country. Almost every Sunday he took his family for an afternoon ride: to the beaches, the mountains, or just through the orange groves to a nearby town. He was the first Mt. Wilson staff member to drive his family up Mt. Wilson. The old toll road, while well maintained, was only one car wide, except for frequent "turnouts' and for the inexperienced it was a real adventure. In 1915 King drove his family to Berkeley, where they spent most of the summer, and frequently visited the Pan American International Exposition in San Francisco. He also took them to Lake Tahoe and to Sequoia National Park.

World War I did not seriously disrupt the observatory's research programs, although King and Harold D. Babcock spent some time developing an acoustical submarine-detecting device that seems to have been a forerunner of the sophisticated and very effective detection devices developed during World War II. By 1918 the war had created a shortage of physics instructors at Berkeley, and King was asked to come and help teach. He obtained a leave of absence from the observatory and took his family with him to Berkeley for several months.

King lived most of his adult life during what this writer considers the golden age of Southern California, say, between 1900 and the beginning of World War II. The countryside, originally semidesert, was beautiful, with the alluvial slopes at the base of the mountains covered with citrus groves interspersed with attractive and prosperous small towns. The lower-lying portions of the river valleys were devoted to alfalfa fields and dairy and vegetable farms. Smog was not yet a problem, nor was overpopulation or traffic. In fact, Southern California was a delightful place to live and was appreciated by easterners and midwesterners, who moved there in large numbers. Industry was mainly engaged in services and construction. Manufacturing was small scale and located mainly in east Los Angeles. It was a favorable atmosphere for scientific research; the observatory thrived and its neighbor, the California Institute of Technology, began its development into a great research institution, due in large part to the efforts of George E. Hale.

Beginning in 1909 King developed his well-known temperature classification of spectral lines of the elements. His earliest publications indicate he had always been interested in the differences in the relative strengths of lines in a given spectrum with the degree of excitation. The graphite tube electric furnace made it possible to sort out lines that appeared at different known temperatures and strengths with increasing temperature and were therefore presumably associated with different energy levels in the atom. He thus proceeded to adopt an arbitrary scale of estimates of relative intensity of lines in a given spectrum and associate it with the temperature at which the lines appeared. The lines that appeared at the lowest temperatures usually below 2000° and strengthened rapidly with increasing temperature were designated Class I. Classes II, III, and IV designated lines appearing at increasingly higher temperatures. Class V included lines that first appeared at high temperatures but were much stronger in the arc spectrum. King's intensity estimates were meticulous and very consistent. These intensity estimates and the temperature classifications proved to be key ingredients in the later-term analyses of the complex spectra of the metals and rare earths. In nearly all of his observations over a period of almost forty years King used a concave grating spectrograph of 15-foot focus in a Rowland mounting in a vertical rather than the usual horizontal arrangement. The grating was located in a pit that ensured quite constant temperature, and the plate holder was mounted on a convenient horizontal track above floor level.

Because of Hale's interest in the magnetic splitting of the many lines observed in sunspot spectra, the laboratory acquired a large Weiss electromagnet capable of producing fields up to 30,000 gauss. King and others used this to record spark spectra of several metals and to measure the Zeeman splitting of many lines. In later years these data also proved useful and often conclusive evidence in the identification of the terms involved in transitions. However, of greater importance in the 1920s and 1930s to those involved in the term analysis of complex spectra were King's estimated intensities and temperature classifications of lines. They furnished clues and often unique evidence about the ordering of the electronic energy levels in the atom. King continued this work throughout the 1920s and 1930s, in fact until his retirement. In the late 1920s King became interested in the spectra of the rare earth elements; accurate wavelength measurements had not been done on many of them. The main reason for this was the difficulty in obtaining pure samples of these elements. Usually samples contained mixtures of two or more rare earth elements, and consequently spectroscopic observations were discouraging.

King contacted a retired industrial chemist named McCoy who was making a hobby of purifying rare earths. McCoy's samples enabled King to make wavelength measurements, furnace arc, and spark intensity estimates as well as temperature classifications of their spectral lines. These data were basic to the term analysis of these very complex spectra. It is not too much to say that probably little would have been accomplished for a long time in the term analysis of rare earth spectra without King's data. King continued his observations of rare earth spectra until his retirement in 1943.

The graphite tube furnace also led to the discovery of an important isotope. The furnace at higher temperatures brought out the band spectra of the characteristic molecules CN and C_2 (CN because of residual air in the furnace enclosure). King had often recorded spectra of the CN bands and also the carbon bands called the Swan bands whose primary head lay in 4737 angstroms. This band had been identified as belonging to the diatomic molecule C_2. Furnace spectra at high temperature and long exposure showed a much fainter but almost identical band head at $\lambda4744.5$ with the resolved components degrading in intensity toward the violet as did those associated with the strong $\lambda4737$ band. The faint 4744.5 band had also been observed in the spectra of N-type stars, the co-called carbon stars. King had suspected for some time that these faint bands were probably due to the presence of the isotope C^{13} forming with the dominant isotope C^{12} the molecule $C^{12}C^{13}$. Since the presence and relative strength of the 4744.5 band was consistent in the furnace spectra at high temperature, the isotope was probably stable (unlike the later-discovered isotope C^{14}). The theory of diatomic molecular spectra or band spectra was still in the process of development, and King invited one of those who was engaged in this work, R. T. Birge of the University of California, to collaborate. They published a paper in *Nature* announcing the discovery of the carbon isotope of mass 13. The comprehensive paper by King and Birge was published in 1930 in the *Astrophysical Journal.* The position of the band head and the wavelength of the secondary lines matched exactly those predicted by theory for the molecule $C^{12}C^{13}$. This identification also, of course, solved the mystery of the presence of the faint band head in spectra of carbon stars mentioned above.

During the 1930s King continued his observations of furnace spectra, particularly of the rare earths; in fact, he did so until his retirement. In 1936 he collaborated with his son, Robert, in developing a method using the graphite tube furnace for the quantitative measurement of the true relative strengths of lines in complex spectra. These data were desired by astronomers studying high-dispersion stellar and solar spectra. Thus, it can be said that the majority of King's work in the team was directed toward providing data for astrophysical applications; his wavelengths, line intensity, and temperature classifications were essential ingredients to the term analyses of complex spectra, which were necessary for interpretation of solar and stellar spectra.

In 1941 King served as president of the Astronomical Society of the Pacific, one of the oldest astronomical societies. He also served a term as president of the American Meteorical Society in the 1930s.

King retired in 1943 and soon became involved with war work at CalTech, where he joined a project concerned with the underwater ballistics of aircraft torpedoes. He continued with this work for several years after the end of the war when the project was taken over by the U.S. Navy but remained in Pasadena.

Good health had been as asset to King since his early youth and permitted him to remain active long after retirement. However, in the mid-1950s he overextended himself on an automobile trip with his wife to Oregon and never really recovered his full strength. His health failed rapidly in 1957, and he passed away in his sleep on April 25th in Pasadena. He left his wife, two sons, and four granddaughters.

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