Biography of Ho-Kwang Mao



A Pioneer of High-Pressure Science and His Quest to Recreate the Earth's Interior

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Introduction



In 1976, at the Geophysical Laboratory of the Carnegie Institution in the United States, Ho-Kwang Mao and his colleague Peter Bell improved diamond anvil cell (DAC) technology, achieving a static pressure of one megabar (1 Mbar), equivalent to one million atmospheres, in the laboratory for the first time. This was twice the highest pressure previously achieved under laboratory conditions. Two years later, the figure was increased to 173 GPa, approaching the pressure conditions of the Earth's outer core.

For high-pressure science, this represented a fundamental breakthrough. Before then, scientists had been restricted to studying the behaviour of matter at relatively low pressures or

relying upon the momentary shock waves generated by explosions. Although such shock waves could produce extremely high pressures, they lasted only briefly, making precise measurements difficult. Mao's advances in diamond anvil cell technology enabled scientists to recreate pressures comparable to those deep within the Earth and observe the behaviour of materials under these extreme conditions.

From Shanghai to Rochester, New York, and from National Taiwan University to the Carnegie Institution, Mao devoted nearly sixty years of scientific research to advancing the limits of experimental pressure, from one megabar to 550 GPa. His journey took him from an enthusiastic student of physics to one of the founding figures of modern high-pressure science. Recognised as a pioneer in the field, he became a member of the United States National Academy of Sciences, a Foreign Member of the Chinese Academy of Sciences, a Foreign Fellow of the Royal Society and an Academician of Academia Sinica. His honours include the Bridgman Gold Medal, the Roebling Medal and the Balzan Prize, among the most prestigious distinctions associated with high-pressure science.

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Chapter 1
Childhood in Shanghai: An Unconventional Student Amid the Turmoil of War

Ho-Kwang Mao was born in Shanghai in 1941. His ancestral home was Jiangshan in Zhejiang Province, a county-level city in southwestern Zhejiang known for the spectacular landscape of Mount Jianglang. During the War of Resistance Against Japanese Aggression, his family moved frequently. From the time he began primary school, he experienced repeated displacement caused by war. Changing homes, transferring between schools and repeatedly saying farewell to newly acquired classmates became defining features of his childhood. These unsettled experiences may have helped him develop an unusual adaptability to uncertainty and a willingness to confront unfamiliar circumstances.

During secondary school, Mao was regarded by his teachers and classmates as an unconventional student. He was particularly interested in mathematics, physics and chemistry, actively participating in extracurricular science groups. Yet when conducting experiments, he frequently ignored the procedures prescribed in textbooks or demonstrated by his teachers, preferring to develop his own methods. His experiments often failed, but occasionally produced small inventions. When solving mathematical problems, he did not necessarily apply the formulas provided in textbooks, instead

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attempting to devise alternative solutions. One mathematics teacher once remarked in exasperation: “I have taught countless students over so many years, but I have never taught anyone as strange as you.”

What appeared unusual was, in essence, an unwillingness to accept standard answers without questioning them. Mao disliked simply following established procedures. He preferred discovering new approaches. This characteristic later became one of his greatest strengths when confronting technical problems in high-pressure science that no one had previously solved.

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Chapter 2
From National Taiwan University to Rochester: Training in Geophysics

In 1963, Ho-Kwang Mao graduated from National Taiwan University with a bachelor's degree in Geology. That same year, he travelled to the United States for advanced studies, entering the Department of Geophysics at the University of Rochester in New York State.

The transition from Taiwan to New York, and from geology to geophysics, represented a significant expansion of his academic perspective. Geology investigates the materials that constitute the Earth, while geophysics seeks to understand the physical processes occurring within the planet. High-pressure science, which examines the behaviour of matter under extreme compression, provides an essential connection between these disciplines. To understand what occurs deep within the Earth, scientists must determine how materials behave under the extraordinary pressures found there. This requires recreating those conditions in the laboratory.

At the University of Rochester, Mao encountered two mentors who profoundly influenced his scientific development: Bill Bassett and Taro Takahashi. In 1964, Bassett and Takahashi identified the hexagonal close-packed structure of iron and introduced Mao to diamond anvil cell technology. He obtained

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his master's degree in 1966 and his doctorate in 1968. His master's thesis examined the equation of state of iron alloys, a subject that would remain central to his research over the following four decades.

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Chapter 3
The Carnegie Years: From One Megabar to Pressures Beyond the Earth's Core

In 1968, Ho-Kwang Mao joined the Geophysical Laboratory of the Carnegie Institution of Washington as a postdoctoral researcher. In 1972, he became a permanent member of its research staff. He subsequently remained associated with the institution for more than fifty years.

The Carnegie Institution is one of the most distinctive research organisations in the United States. It does not award academic degrees and does not seek institutional expansion for its own sake. Instead, it concentrates on fundamental scientific discovery. Its Geophysical Laboratory became an internationally recognised centre for high-pressure science and mineral physics. There, Mao found an environment ideally suited to his interests: a place where he could devote decades to pushing the boundaries of experimentally achievable pressure.

In 1976, working with Peter Bell, Mao advanced diamond anvil cell technology to achieve a static pressure of one megabar, equivalent to 100 GPa. In 1986, he and colleagues including Xu Ji'an established a world record for static pressure of 550 GPa. This exceeded the approximately 370 GPa pressure at the Earth's centre and approached conditions found within the

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interiors of Saturn and Jupiter. Mao was among the first scientists to push laboratory pressures beyond the megabar threshold, extending humanity's ability to reproduce extreme physical conditions to an unprecedented level.

Yet Mao's contributions extended far beyond simply achieving higher pressures. More importantly, he helped develop a comprehensive range of techniques for making precise measurements under extreme compression. Working with colleagues, he incorporated laser heating, synchrotron X-ray techniques, neutron scattering, Brillouin scattering, Raman spectroscopy, infrared spectroscopy and nuclear magnetic resonance into diamond anvil cell experiments. These advances enabled scientists to measure the structural, elastic, electrical, magnetic and optical properties of materials directly under pressures reaching millions of atmospheres.

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Chapter 4
Recreating the Earth's Interior: From Iron Spin Transitions to Hexagonal Diamond

Ho-Kwang Mao's research has consistently revolved around one fundamental question: what is the interior of the Earth really like?

Under pressure and temperature conditions comparable to those within the Earth's core, his research team systematically investigated the structures, elastic properties, rheological behaviour, chemical characteristics and electronic properties of more than one hundred oxides, sulphides, silicates, hydrous minerals, metals and alloys. They measured the phase diagram and melting curve of iron under core conditions, helping resolve controversies that had persisted for decades. They also identified spin-pairing transitions in iron within deep-mantle silicates, processes that influence elemental differentiation, elasticity and radiative heat transfer.

These findings provided a physical foundation for interpreting seismic observations. The velocities and paths of seismic waves travelling through the Earth depend upon the elastic properties of the materials they encounter. Understanding those properties under extreme pressure requires direct laboratory measurements. Mao's work therefore helped establish a comprehensive body of experimental knowledge

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about the physical characteristics of materials within the Earth's interior.

In 2021, Mao's research team turned its attention to an even more fundamental problem: hexagonal diamond. In 1962, theoretical physicists had predicted the existence of this carbon allotrope, described as possessing a structure potentially superior to that of conventional cubic diamond. Evidence of its presence was discovered in meteorites in 1967. Yet for more than sixty years, scientists had struggled to synthesise high-purity, large-sized hexagonal diamond in the laboratory. Its ideal structure had remained extraordinarily difficult to reproduce experimentally.

Collaborating with researchers from the Center for High Pressure Science and Technology Advanced Research in Beijing and the Xi'an Institute of Optics and Precision Mechanics of the Chinese Academy of Sciences, Mao spent more than a decade investigating the problem. The team eventually succeeded in synthesising hexagonal diamond-like single-crystal bulk samples from graphite, with dimensions ranging from hundreds of micrometres to the millimetre scale.

The resulting paper underwent a prolonged review process at Nature, lasting approximately four years and involving more than a dozen rounds of exchanges with reviewers. Mao regarded the experience as a valuable form of scientific

pressure. As he observed: “Good science is not afraid of being refined. What it should fear is having nobody willing to refine it seriously.”

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Chapter 5
Honours and Recognition: An Extraordinary Record in High-Pressure Science

Ho-Kwang Mao's record of scientific honours is exceptionally distinguished within the field of high-pressure research.

In 1989, he received the P. W. Bridgman Gold Medal from the International Association for the Advancement of High Pressure Science and Technology (AIRAPT). Named after Percy Williams Bridgman, a founding figure of modern high-pressure science, the medal is one of the field's highest distinctions.

In 2005, Mao received three major honours: the Gregori Aminoff Prize in Crystallography from the Royal Swedish Academy of Sciences, sometimes described as the Nobel Prize of high-pressure science; the Roebling Medal from the Mineralogical Society of America, its highest honour; and the Balzan Prize, awarded by the Balzan Foundation associated with Italy and Switzerland.

In 2007, he received the Inge Lehmann Medal from the American Geophysical Union (AGU), recognising his outstanding research contributions to understanding the structure, composition and dynamics of the Earth's mantle and core.

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Mao was elected to the United States National Academy of Sciences in 1993, became a Foreign Member of the Chinese Academy of Sciences in 1996, was elected an Academician of Academia Sinica during the 1990s, and became a Foreign Fellow of the Royal Society in 2008. In recognising his achievements, the Royal Society praised the extraordinary creative influence he had exerted over more than forty years in the development of high-pressure science and related technologies.

In 2002, Mao received the Friendship Award from the Chinese government in recognition of his contributions to scientific development in China. In 2011, he became Director of the Center for High Pressure Science and Technology Advanced Research in Beijing, bringing the techniques and experience accumulated during his career at Carnegie to China and helping advance the country's capabilities in high-pressure research.

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Chapter 6
Concluding Reflections: The Public Value of a Scientist Who Recreated the Earth's Interior

Ho-Kwang Mao's life can be summarised through one idea: recreating the Earth.

What he recreated was the physical environment of the Earth's deep interior. Within the minute space between two diamonds, he generated pressures comparable to those found at the planet's centre. Inside this miniature representation of the Earth's core, he investigated how iron melts, how silicates undergo phase transitions and how hydrogen may transform into a metallic state. His work made it possible to investigate the Earth's interior experimentally, not merely through theoretical predictions or computational models, but through direct physical measurements.

He was also a scientist who developed the instruments required for discovery. Throughout his career, he devoted considerable effort to improving diamond anvil cell technology and developing new methods of measurement. Rather than simply conducting experiments with existing equipment, he belonged to a tradition of experimental scientists who created new instruments because their research questions demanded capabilities that did not yet exist. This ability to develop

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experimental technology was central to his sustained leadership in high-pressure science over half a century.

From a childhood disrupted by war in Shanghai to doctoral research in geophysics at Rochester, and from a postdoctoral appointment at Carnegie to receiving many of the highest distinctions in high-pressure science, Mao followed an extraordinary scientific journey. His achievements ranged from establishing a world record of 550 GPa to contributing to the resolution of longstanding questions surrounding hexagonal diamond.

Over more than eighty years of life, Ho-Kwang Mao developed from an enthusiastic student of physics into a scientist capable of recreating the extreme conditions of planetary interiors. His story illustrates an important principle of experimental science: some of the most valuable contributions are not theories that explain observed phenomena, but technologies that make previously inaccessible phenomena observable.

Ho-Kwang Mao was a scientist who used the diamond anvil cell to recreate the pressures of the Earth's interior and, in doing so, helped make the hidden physical world deep beneath our feet accessible to scientific observation.

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