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The 14-billion Year History of the Universe Leading to Modern Materials Science

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The story begins approximately 13.8 billion years ago with the Big Bang. A brief introduction will trace the evolution of the universe to what we observe today. Many of the formative events occurred in the first tiny fractions of a second (our universe evolved from consisting entirely of a quark/gluon plasma to form the first hadrons: protons and neutrons) to minutes (free neutrons decay to electrons, neutrinos, and more protons) to a few tens of thousands of years (elementary particles react to form the first elements which leads, in turn, to the development of stars due to local density fluctuations). Planet Earth nucleated and began to accrete interstellar debris ~ 4.5 billion years ago. While the lighter metal elements on earth formed primarily due to stellar supernovae explosions, the primary mechanism leading to the formation of the heavier elements has only recently been demonstrated. The first known sophisticated stone tools used by hominids, found in northern Ethiopia, date to 2.6 million years ago.

Gold is likely the first metal discovered by man, $>11,000$ years ago. However, unlike copper (Mesopotamia, ~ 9000 BC), bronze (Iran, ~ 5000 BC), and cast iron (China, ~ 600 BC), it was too soft for fabrication of tools and weapons. Instead, gold was used for decoration, religious artifacts, and commerce. Spectacular metal sculpting displaying very high levels of metallurgical and artistic craftsmanship have been found in Mesopotamia (S. Iraq). The earliest high-purity Au artifacts derive not from Egypt, as commonly thought, but from NE Bulgaria ~ 6500 y ago; however, the largest known concentration of ancient gold mines is in the Egyptian Eastern Desert. Metal extraction from ore, copper smelting, was already being carried out in the Balkans (E. Serbia and S. Bulgaria) ~ 7500 years ago.

Gold brazing of metal parts was first reported in ~ 3400 BC in Sumaria. The earliest documented thin metal films were gold layers, some less than 1000 \AA thick, produced chemi-mechanically by Egyptians ~ 5000 years ago. Examples, gilded on copper and bronze statues and artifacts (requiring sophisticated compositionally-graded interfacial adhesion layers), were found in hewn-stone pyramids dating to ~ 2650 BC in Saqqara. Spectacular samples of embossed gold sheets date to at least 2600 BC. Electroless gold and silver plating was developed much later by the Moche Indians of Peru in ~ 100 BC.

Early biomaterials used as human prosthetics following successful amputations date to 950 BC in Egypt, while the first recorded quantum-mechanical nano-based devices, exhibiting spectacular dichroic nanophotonic effects based on $\sim 200\text{-\AA}$ -diameter Au alloy quantum dots, were synthesized in Rome during the early third-century AD.

Vapor-phase deposition of thin metal and ceramic films on bulk substrates (as used in manufacturing of today's transistors, hard discs, LED TVs, etc.) had to wait for the invention of vacuum pumps (~ 1650 for mechanical pumps, through ~ 1865 for ballistic mercury momentum-transfer pumps). The fascinating development of crystallography (Plato [Greece], 360 BC; through Kepler [Germany], 1611; Haüy [France], 1780s; and Miller [UK, 1839]), is essential for describing crystal structure in modern materials science, mineralogy, and geology.

While an historical road map tracing the progress of materials technology is interesting in itself, the stories behind these developments are even more remarkable and provide insight into the evolution of scientific reasoning.

Primary author: Prof. GREENE, Joe (D.B. Willett Professor of Materials Science and Physics, University of

Illinois; Tage Erlander Professor of Physics, Linköping University, Sweden; University Professor of Materials Science, National Taiwan Univ. of Science and Technology)

Presenter: Prof. GREENE, Joe (D.B. Willett Professor of Materials Science and Physics, University of Illinois; Tage Erlander Professor of Physics, Linköping University, Sweden; University Professor of Materials Science, National Taiwan Univ. of Science and Technology)

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