Christopher Hall

MATERIALS

A Very Short Introduction

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Preface

Useful matter is a good definition of materials. It covers engineering stuff like steel, concrete, rubber, plastics, wood, semiconductors, glass, and aluminium. But it stretches to oil and gas, food, agrochemicals, pharmaceuticals, explosives, textiles, and dyestuffs. It also has room for oddball things like ivory and invar, graphite, grease, porcelain, and paint. So it should. All these materials are useful to us. Materials are materials because inventive people find ingenious things to do with them. Or just because people use them.

The link between materials and users takes us beyond science and engineering, into medicine, and on into economics, history, and culture as well. Materials flow through the world economy in prodigious amounts, and commodity markets fix the prices of oil and gold. Industries grow and die; steel production moves from Europe and North America to Asia. A development economist describes the scavenging of waste plastic in India's informal economy. Anthropologists analyse material culture, and how pots and solar lamps work in societies and groups. The archaeological record consists mostly of material objects. Materials shape communications, the media, architecture, building, and the fine arts.

Most new technology depends in some way on innovation in materials. All advanced economies spend vast sums of money on materials research. Materials production is the business of big industries like steel and semiconductors. But it was so in all historical periods: from the Silk Road to Silicon Valley. After the Second World War the importance of materials in industry and economics was as clear as day. The universities were prodded by industry labs at General Electric and Bell Telephone, and by the military. Materials science appeared as an academic discipline in the 1960s, first in the USA at Northwestern University, then at Penn State, and rapidly after that in universities worldwide. Materials science today explains how materials are made and how they behave as we use them.

But this book is not a synopsis of materials science, although you will see the kind of explanations of material behaviour that materials science provides. I am taking a broader view. Even scientifically, there is more to materials than materials science. Engineering has been and is the source of much of what we know about materials, for example how we use them in large-scale structures like bridges. In the 19th century engineers and mathematicians together worked out how to describe the strength of materials. Industrial manufacturing in iron and steel, in pottery, in glass and in textiles provided more new knowledge. Much has come from chemists working on every element of the Periodic Table, and since the 1920s from physicists who brought quantum mechanics to bear on the properties of solids. And from others who invented scientific instruments.

I start with a mixer in Chapter 1 to introduce materials of many kinds, from scientific, industrial, and sometimes historical viewpoints. Chapter 2 parachutes down into the microscopic architecture of materials to see how they are constructed (and how we know). Chapters 3 and 4 describe the diverse properties of materials that make them useful, and to some extent how we explain these properties. In Chapter 5, I look at how we make materials, and how we make things from them, which is ultimately what we care about. And finally in Chapter 6, I try to make sense of the problem of sustainability.

I am grateful to many people for helping with comments and advice. In particular I thank David Coates, Ken Entwistle, Simon Finch, Mike Goulette, Ben Hall, Liza Hall, Andrew Harrison, Bill Hoff, Ying Jiang, Vassilis Koutsos, Geoff Maitland, Pablo Maldonado, Richard Nelmes, Elio Raviola, and Nick Rowley.

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Chapter 1
Gold, sand, and string

All about us is an uncountable profusion of materials. Gold, sand, and string are just three random picks, but they are wonderfully dissimilar. And these three materials can stand also for the metallic, the inorganic, and the organic resources on which we draw. Gold leads us to bronze, and to iron; sand to stone, to clay, and eventually to silicon; string to rope, and cloth, wood, and rubber.

It is from the particularities of substances that uses arise. So, first to gold.

Old money

Pure gold coins, stamped with a lion and a bull, were made in Anatolia in the 6th century BCE under the rule of King Croesus (Figure 1).

This marks an important moment in the invention of coinage. These croeseids, looking like jelly beans by Fabergé, each weigh about 8 grams, and each is composed of about 25 billion trillion atoms of gold. Because the element gold has only a single stable isotope, ^{197}Au, every one of these atoms is identical in structure and mass. In making the coins, the gold is melted, and on cooling the atoms which are in complete disorder in the molten metal