SAMPLE

Plasma Physics

The Fourth State of Matter

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This free sample contains the Introduction and Chapter 1. The complete book contains the full contents above.

Introduction

Plasma is the state of matter that almost everything is made of. The stars are plasma. The space between the stars is plasma. The wind from the Sun that brushes past Earth every day is plasma. The glowing gas in a neon sign, the arc of a welding torch, the filament of a lightning bolt: all plasma. By the standard estimates, more than ninety-nine percent of the ordinary matter in the visible universe is in this state, which makes the solids, liquids, and gases of everyday experience a kind of local curiosity, a cold corner of a very hot cosmos.

The name arrived in 1928, when the American chemist Irving Langmuir, watching an ionized gas carry electrons and waves, was reminded of blood plasma carrying corpuscles. The joke became the standard word, and the thing it names is simple to state and strange to hold: a plasma is a gas so hot or so energized that its atoms have lost some or all of their electrons, leaving a swarm of charged particles that responds, collectively, to electric and magnetic fields. That last word, collectively, is what makes plasma a fourth state rather than a warm gas. In an ordinary gas, each particle minds its own business. In a plasma, the particles push and pull each other at long range through the fields they carry, and the gas begins to behave like a single creature with moods.

Those moods are the subject of this book. A plasma can be quieter than any gas or noisier than any solid. It can hold shapes no cold matter could keep, trap particles in invisible magnetic bottles, hurl jets from galaxies tens of thousands of light-years long, and refuse, after eighty years of the best engineering on Earth, to sit still long enough to run a power plant. The physics of this refusal is honest, hard, and partly open.

The tour keeps the series' rules. No equations: every idea appears in plain words, and the few numbers that appear are dates, temperatures, and plain distances rather than algebra. The people are treated as people, not monuments. Settled facts are marked settled; open questions are graded open, with the evidence named; and popular myths, including a few that live comfortably in documentaries, are graded dead. The book begins with the state itself and the grammar that makes it a state, follows the scientists who domesticated it, walks through the laboratory and out into the solar system, examines the fusion project that is the subject's most expensive ambition, and closes with a farewell that hands the reader the one image that holds the whole subject.

Chapter 1: The Fourth State

A solid holds its shape because its atoms are locked to their neighbors. Heat it and the lock breaks: the atoms slide, and the substance flows as a liquid. Heat it further and the sliding stops being a relationship at all: the atoms fly apart as a gas, touching nothing but the walls. The schoolroom story ends there, with three states, and for the kitchen it is a true story. The cosmos tells a different one. Add still more energy, enough to strip electrons off the atoms themselves, and the gas changes character once more. It is no longer a crowd of neutral particles but a mixed population of negative electrons and positive ions, and each member of that population carries an electric charge.

That charge is the whole revolution. A neutral atom ignores a passing field; a charged particle obeys one. Put an electric field across an ordinary gas and nothing much happens, because the gas is an insulator: this is why air between two wires stays quiet at low voltages. Put a strong enough field across it and, at breakdown, the air ionizes along a channel, the channel becomes a conductor, and the result is a spark. The gas that was refusing to carry current a moment ago is now carrying it enthusiastically. The state that does this has its own name and its own physics, because the charged population does things no neutral gas can do.

The transition is not a chemical reaction. The substance is the same substance; neon is neon before and after the sign is switched on. What changes is the accounting. In a neutral gas, every atom has matching positive and negative charges, so the net charge of any particle is zero. In a plasma, the charges are separated and mobile, and their motion is what the field acts on. The separation is usually small: most laboratory plasmas are only partly ionized, a whiff of charged particles moving through a majority of neutral atoms. Even a fraction of a percent of ionization can dominate the behavior, because the charged minority responds so strongly to fields. A gas with one ionized atom in ten thousand can act, for electrical purposes, like a metal.

The phrase fourth state of matter is older than the modern understanding. In 1879 the British physicist William Crookes, studying the glow inside his evacuated tubes, called the glowing region radiant matter and suspected it was a state beyond gas. The suspicion was right even where his details were wrong, and the tubes he built became the ancestors of neon signs, fluorescent lamps, plasma screens, and half a century of atomic physics. The full picture waited for the twentieth century, when the study of electric discharges, radio waves bouncing off the sky, and the new science of the ionosphere all converged on the same conclusion: this glowing, conducting, wave-carrying gas was not a variety of gas at all but its own subject.

The scale of the subject is the largest in physics. Ordinary matter, the kind made of atoms rather than the dark matter whose nature is another book's question, is overwhelmingly plasma where it is hot enough to be ionized, and the universe is overwhelmingly hot enough. The Sun is a ball of plasma heated by fusion at its core and kept ionized throughout by its own temperature. The space between stars, thin beyond any laboratory vacuum, is a plasma because even at densities of one particle per cubic centimeter, ultraviolet light from hot stars keeps the gas ionized. The solar wind, the Sun's escaping atmosphere, carries plasma past Earth at hundreds of kilometers per second. By visible weight, the solid worlds of the solar system are a rounding error in a plasma universe.

The state is also, despite its cosmic dominance, the least domesticated. Solids can be held in the hand, liquids poured, gases bottled. A plasma at the temperatures where it is interesting would end any container made of atoms, and the effort to hold it anyway, with magnetic fields instead of walls, is the fusion project described in this book's middle chapters. That effort has consumed national budgets and scientific careers, and its ledger of progress and delay is kept honestly here, because the plasma refuses to pretend.

A fair question to ask of a fourth state is where its borders are. Dry air is not a plasma; a candle flame, though slightly ionized, barely qualifies; the ionosphere, a hundred kilometers up, qualifies without argument. The working borders are set in the next chapter, not by a temperature line but by two tests of distance and behavior, because a plasma's definition is not how it was made but what it does.

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ABOUT THE AUTHOR

Aira Astralis is a science writer specializing in astronomy and space exploration. Her work spans the full breadth of humanity's relationship with the cosmos -- from the earliest naked-eye observations to the engineering marvels of modern space missions.

Her books are built on a foundation of primary sources: peer-reviewed research, mission archives, and direct engagement with the scientific community. She writes for readers who want to understand not just what we know about the universe, but how we came to know it.

She believes that the most important frontier is not out there but in the gap between what scientists discover and what the public understands. Her books exist to close that gap.