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Matter: The Stuff the World is Made of

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The nature of matter, or body considered in general, consists not in its being something which is hard or heavy or coloured, or which affects the senses in any way, but simply in its being something which is extended in length, breadth and depth.

René Descartes

Introduction: ***On the whole, this is not a material world at all.***

Matter is the most striking feature of perceived reality. It is all around us, on us, and within us too. We recognize the world primarily through gross matter. We see things, touch things, taste things, and smell things: all this constitutes much of perceived reality. From these we are tempted to conclude that the universe is essentially material, consisting of a whole range of tangible entities, from tiny particles of dust and sand to large planets, massive stars and stupendous galaxies. Matter seems to be the stuff the universe is made of.

The definition of matter is no easy matter. For our purposes, matter may be considered as that tangible something whose existence (as a component of perceived reality) can be felt, experienced, and established directly or in indirect ways. Matter always requires some space – a tiny little region or a much larger volume. At our level at least, as Descartes noted, all matter has extension.

Ordinarily, we find matter in one of three states. Some materials are solid as rock, others like water and oil are free-flowing liquids, yet others are tenuous, like air or water vapor. There is also a fourth state of matter, called *plasma*, to which all matter is transformed when raised to incredibly high temperatures.

The material universe is more empty than filled, which means that the universe happens to be material only here and there in the vastness of its expanse. In fact, the density of matter in the universe is said to be a paltry 3×10^{-28} kilograms per meter cube. This figure comes from very rough estimates of galactic masses and the volume of the universe. This also does not include the so-called missing-mass problem[1]. In any case, to an outside observer – if there is one – the

[1] For a popular discussion of this, see, John Gribbin, *In Search of the Big Bang: Quantum Physics and Cosmology*, Bantam Books, New York, 1986.

universe would be one gigantic wasteful void, with sprinklings of matter here and there, somewhat like a dozen or so boats sailing alone in the vast expanse of the seas. In truth, therefore, this is not a material universe[2] at all, but a radiant one, for its entire span is perpetually bathed in vibrant radiation.

Though the material components of the universe occupy but a negligible fraction of space compared to its totality, they are interesting in their marvelous properties and variety. They are also important because without them there would be no universe at all. The droplets of matter strewn in the vast stretches give body, identity, and bounds to the physical universe.

In our own realm of everyday experience, we rarely encounter emptiness: it is matter, matter everywhere, and no vacuum seen. We use the term mass to indicate the amount of matter constituting a physical body. Our earth, dimensionally speaking, is an insignificant material speck in a universe much of whose matter is concentrated in countless stars. These stars are of unimaginably larger dimensions and considerably more mass-packed.

Variety of Matter: ***Nature and humans have created variety in matter.***

There is an endless variety of matter in our world, a staggering assortment of things that make *terra nostra* such as it is, adding immeasurable charm and beauty to perceived reality. There is sand and stone, water and wood, mud and mica, and much more. No matter, no world no doubt; but could not the world been made with just one kind of matter? Perhaps, but it is not, and if it had been, how dreadfully boring it would be! Initially, the world had matter of one kind only: hydrogen to be exact, but soon other substances were formed from it. How this happened is more thrilling than the dénouement in any detective story. Nature seems to have known what we all, like Euripides, feel: *Variety is sweet in all things.* As if Nature has not done a sufficient job, human ingenuity has concocted even more kinds of matter: from pliable plastics and deadly dichloro-diphenyl-trichloroethane (DDT) to countless other substances in laboratories and factories[3]. We continue to synthesize materials every waking day: to relieve pain, to cure ailments, to make better floors, to satisfy a thousand other need and greed. A million new substances have been brought into existence by human beings.

Every different manifestation of matter behaves differently, or as one reads in science texts, each has its own unique properties. These properties could sometimes change under changing conditions. Thus the same substance may be solid ice, liquid water, or tenuous vapor, depending

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[2] But it was not always so. In the beginning, according to the *Book of Genesis* of current cosmology, the density of the universe was a fantastic and inconceivable 1090 kilograms per cubic centimeter.This is known as the *Planck density*.

[3] According to one estimate more than 56 million organic and inorganic compounds have been listed.

on its temperature. Materials may be hard or soft, rough or smooth, light or heavy, conducting or not conducting of heat, green or red or of some other color, on and on one can go in their description. These are some of their *physical* properties.

Then there is enormous richness in the range of the *chemical* properties of substances: how they burn and transform, how they store up or spill out energy in the process, how they combine with other materials or remain aloof, and so on. These too have been studied and listed in countless volumes. The ability and propensity of matter for chemical change is what keeps our nook in the universe picturesque, panoramic, and throbbing with life. If the planet's conditions inhibited chemical transformations, everything would be frozen stiff in a permanence that would endure forever maybe, but it would all be inert and unchanging, dismal as in the silent darkness of distant Pluto which is a lifeless dungeon as far as we can reckon, whether we call it a planet or not.

In this context it is good to recognize that chemists have for long been studying the characteristic properties of a million different substances painstakingly and with meticulous attention to details. They have been classifying and connecting them, breaking up and reconstructing the bonds that sustain them. By the penetrating power of the human mind, aided by carefully collected data on chemical reactions, we became aware of atoms and molecules, of chemical bonds and structures, long before these were put into evidence by instruments that probe deep into the core of matter.

Elements and Compounds: *Substances are either simple or complex.*

The universe is a complex system from simple things. Though at the experiential level we are struck by the variety and splendor in the matter around us, as we penetrate into the deep recesses of the material world, we begin to discern surprising simplicity. It is not a barren simplicity, however, but a marvelous one, rich in consequences, fruitful in expressions.

The ancients had a sneaking suspicion that this was so, for many old cultures imagined primary elements from which the material world arose. One of the earliest record we have of the universe evolving from some primordial stuff is in the *Vedas* where one uses the notion of *sat* (pure being or essence) as having given rise to the world. There was a man by the name of Uddalaka Áruni in ancient India who not only hypothesized that from a primordial principle there arose a creative energy (*tejas*) from which came water and food. Water gave rise to life and food to the mind, he went on to hypothesize, and also attempted to demonstrate it[4]. Thales of Miletus thought similarly that everything emerged ultimately from water, for which reason Aristotle

[4] *Chhandogya Upanishad.*

referred to him as the first philosopher. He is also regarded as the founder of naturalistic science in the Western tradition[5].

Recognizing the three states of matter as seen in land, sea, and air, the ancients were prompted to consider *earth*, *water*, and *air* to be the primary substances out of which everything came. Realizing the importance of heat for life and activity, they added *fire* to the list. Wondering at the apparently boundless expanse high above, Indian thinkers included the *sky* (or *space*) to the basic blocks making up our world[6].

It has been a long and searching route, the gradual recognition of the chemical basis of ordinary matter, known to most people today. Today we talk casually about oxygen and helium, of H_2O and CO_2, but even two hundred and fifty years ago – a mere wink in the history of the human race – people knew nothing of these. Only painstaking experiments, critical analyses, and honest efforts at explaining things in logically consistent modes enabled humanity to become aware of the underlying essence in the variety of things.

Thanks to the work and insights of countless investigators like Robert Boyle[7] in the seventeenth and Antoine Lavoisier[8] in the eighteenth century, we now know that beneath all the colorful and uncountable multiplicity of things, there are barely less than a hundred simple substances. We call them *elements*.

The first list of elements, such as we understand the term today, was published by Lavoisier in 1789: the year of the French Revolution whose subsequent Reign of Terror beheaded this founder of modern chemistry[9]. Lavoisier's original list had only thirty three elements, and it began with light and heat. It included such commonly known metals as copper, tin, and gold; the gases oxygen, hydrogen, and nitrogen; as well as mercury, sulfur, and carbon[10]. But others carried on the work thus launched, and we have since then become aware of a multitude more,

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5 Thales of Miletus (sixth century BCE) is regarded as the first philosopher and the first scientist in the Western tradition.

6 Known as *ákásha*, it was also endowed with some esoteric properties, as in the *ákaásha rahasyam* in the Nataraja Temple in Chidambarm. The five elements of ancient science are known as the *mahabhútas* in Sanskrit.

7 Robert Boyle wrote: "I must not look upon any body as a true principle or element, but as yet compounded, which is not perfectly homogeneous, but is further reducible into any number of distinct substances, how small soever".

8 Antoine Lavoisier (1743–94) gave the names hydrogen and oxygen of which he was a discoverer, as also of nitrogen (which he called *azote*).

9 About the atrocious beheading of Lavoisier by the guillotine, the eminent mathematician Josephe Lagrange said: "It took them but an instant to chop off his head, but France may not produce such a one for another century."

10 His list was classified into gases, metals, non-metals, and earths. It had 33 items.

bearing such exotic names as osmium and lanthanum, selenium, indium[11], and rubidium. Not only have we come to know of their existence, we have studied and exploited their properties too.

Delving still deeper into the structure and behavior of matter, we have been able to concoct new elements: That is to say, elements that did not exist, because they could not last for long in the physical world. These are the so-called transuranic elements. We have brought into existence more than a score of them[12]. When I say *we* in these contexts, I am referring to humanity, and especially to the spirit of science in the human family. National and cultural divisions in the context of science can lead to narrow perspectives. The urge to vaunt cultural pride sometimes prompts people to make confused claims.

Chemical elements embrace one another in myriad modes to produce the wondrous variety of substances in the material world. Every piece of matter has one or more of the basic elements, separately or in combinations. Materials which result from the combining of different elements are called *compounds*. In the presence of a piece of matter, we rarely pause to consider what it is ultimately made up of. We do not think of water as consisting of oxygen and hydrogen, or of sugar as a combination of carbon, hydrogen, and oxygen. Nor does red ruby remind us of aluminum and chromium any more than emerald of beryllium and silicon, or diamond of carbon pure. But the splendid spectrum of color and smell, of taste and softness, is all the result of varying affiliations of various elements, often chemically combined. The mixing of materials in specific proportions results in limitless variety.

Being material entities ourselves, we are constrained by physical laws. We are puny in front of Nature's majesty, flimsy in comparison to her stupendous power. Yet in spirit and intelligence, we sometimes accomplish more, such as creating substances that did not exist in Nature before we emerged in the universe.

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[11] The use of Indigo dyes had its origin in India. The color of the dye gave the name indigo which Newton included as one of the seven colors he identified in the spectrum of white light through a prism. The element Indium was named as such because it was discovered (in 1863) by two chemists in the bluish spectral line of a zinc ore that did not correspond to any of the then known elements.

[12] The transuranic elements upto 122 are: 93 neptunium Np; 94 plutonium Pu; 95 americium Am; 96 curium Cm; 97 berkelium Bk; 98 californium Cf; 99 einsteinium Es; 100 fermium Fm; 101 mendelevium Md; 102 nobelium No; 103 lawrencium Lr; Tr104 rutherfordium Rf; 105 dubnium Db; 106 seaborgium Sg; 107 bohrium Bh; 108 hassium Hs; 109 meitnerium Mt; 110 darmstadtium Ds; 111 roentgenium Rg; 112 copernicium Cn. From 113 to 134 they are numbered in Latin as 113 ununtrium Uut (113); 114 ununquadium Uuq (114); 115 ununpentium Uup (115), etc., until 137 Untriseptium (137). This last one is also sometimes known as feynmanium (Fy).

The Structure of Matter: ***Debating and speculating can never tell the truth about reality.***

What then is matter? Let us consider a small chunk of a substance and do a *Gedankenexperiment*[13]. Let us suppose we break it up into two bits and break the smaller one again, and repeat the process again and again. In practice, this would soon become impossible because the little bits would be reduced to invisible specks, beyond the harsh slicing by our instrument. But in our minds we can carry on the process for as long as we please.

Or can we? The question is significant because on its answer will depend how we believe all matter to be. Ancient thinkers gave considerable thought to it and they were split into two schools. There were those who imagined one can go on and on, subdividing indefinitely any material substance, even as one can, in principle, keep chopping a geometrical line till time runs out. Then there were others who asserted we would be forced to come to an ultimate unbreakable unit with any piece of matter. So we had the *plenists* and the *atomists* in by-gone ages.

This question, like all others pertaining to the nature of perceived reality, cannot be decided by mere speculation or by taking votes. It took centuries of experimentation and millennia of debates, for the question to be settled. Every substance, such as we know it, has an ultimate integral unit up to which it preserves its identity. We call this a molecule of the substance[14]. So, in a sense, the atomists were right. However, this ultimate component-brick of any matter is not exactly unbreakable. It can be further cleaved, but when this is done, it loses its identity. Perhaps we may make an analogy with a mound of ants which can ultimately be analyzed into so many identical ants. But if you chop down one of them, the parts cease to be an ant any longer.

Thus, contrary to the etymology of word, atoms can be split[15]. Atoms have structure and

[13] A *Gedanken* experiment (always with a capital G because it is a German noun) means literally a *thought-experiment*. It is experiment which is conducted only in the mind, but one from which interesting possibilities can be derived. Such experiments play a very important role in many branches of science as well as in philosophy and mathematics. Although they have been in use for a long time in the history of ideas, it was Hans Christian Orsted who first used it in a physics context in 1812. But it was Ernst Mach's use of it by the close of the 19th century that gave the word greater currency.

[14] The word molecule literally means a small mass in Latin. It acquired a precise technical meaning only in the nineteenth century, as a result of the works of John Dalton, Amadeo Avogadro, and Stanislao Canizzaro.

[15] The ancient Greek thinker Democritus coined the word *atomos*, meaning that which cannot be cut (any further). Ancient Jain and Hindu thinkers also believed in such ultimate indivisible units of matter. Though the ancient concepts of the atom (Greek, Jain, or Hindu) had no relation whatever to what we mean by the term today, we must admire the thinkers of those times who had the vision to imagine such ultimate material units, so many centuries ago. The use of the term atom in modern chemistry began in the first decades of the 19th century with the work of John Dalton.

components. The recognition of the composite nature of atoms is another intellectual triumph of the twentieth century. For it was then that human ingenuity penetrated into the deepest core of matter, and unraveled the marvels that are continually occurring in the invisible substratum of perceived reality. Here let us simply note that atoms consist of electrical charges, and that they are dynamic and spectacular in how they behave. They have an uncanny resemblance to the solar system where planets orbit around a central star: within the atom too, minute electrons are whirling around massive nuclei. The simplest atom, that of the most common element hydrogen, consists of a single very light negatively charged electron circling around a much heavier positively charged proton[16]. In a carbon atom six electrons are orbiting a nucleus made up of six protons and six neutrons. We may exclaim, like the poet Blake, that we see a world in a grain of atom!

The Structure of Atoms: ***There is more void than matter at the heart of matter.***

Equally remarkable is the essential emptiness that pervades the atomic realm. If the entire atom were enlarged to a territory a few hundred kilometers across, then its central nucleus would be like a cottage somewhere at the center while the circling electrons would be like automobiles moving around in distant beltways. Thus, much of the region between cottage and cars is pure unoccupied space, not unlike the interplanetary nothingness that pervades the solar domain. Indeed, if the mass concentrations within the atoms were forced to come into direct contact with one another, in other words, if the stuff in atoms is squeezed into contiguous proximity, and all the atoms in a substance were forced to touch each other, filling all the available emptiness in between, then a spoonful of matter would weigh a million tons and more.

The atoms themselves are not very close to one another, but are separated by distances significant in relation to their size. Whether in solids or in liquids, and even more so in gases, the constituent atoms never touch one another like people in a crowded subway or sardines in a can. Rather, they are more like trees in an orchard or fish at sea, close sometimes, or far, but never in direct contact. We are reminded of Ralph Waldo Emerson's prescient lines[17]:

> *Atom from atom yawns as far*
> *As moon from earth, or star from star.*

In other words, this perceived reality of gross matter, continuous to all appearances, is in truth an agglomeration of minute entities, like sand grains on a beach, but far too small to be discerned

[16] This is the so-called Niels Bohr model for the hydrogen atom, proposed almost a hundred years ago, in 1913.

[17] These lines are from the poem 'Nature' (fragments on Nature) penned in the 19th century.

as such. Who would have expected that underneath the softness of silky surfaces and deep in the smooth flow of fluids there lurks a granular structure? It is as if a myriad non- touching pebbles formed together a compact whole, their coarseness camouflaged by a deceptive continuity when viewed from a distance. The illusion arises because of the dimensional scale. Our perceptions are at a far too enlarged level, the minute discontinuities are way beyond our sensory recognition.

This too is intriguing to our intuitive grasp of the world. When we hold a piece of matter in hand we are actually touching sheer emptiness, spotted here and there with material centers. And so are our own bodies, and every other piece of matter: gaping emptiness, strewn with material bits like needles in huge haystacks.

Ultimate Entities: ***Ultimately, there are but point concentrations of mass.***

Not only is the atom itself cuttable, so are some of its components. Probing into matter has been compared to the peeling of an onion, for as each layer is undressed what remains seems to have more layers still. But we will not give up until the last dot of perceived reality is spotted. So we have gone deeper and deeper to uncover the ultimate bricks of the material world, armed with the flashlights of elaborate instruments and mighty mathematics.

Each era of physics formulates its own final findings as to where the complexity halts. By the last quarter of the twentieth century, physics painted a picture of the root of matter that is cogent and colorful, and claiming at least as much finality as what our predecessors had claimed about theirs. We shall glimpse into the details of this picture later. Here we simply note that on the basis of whatever we know and think today, the material world seems to be constructed of three principal kinds of point-mass concentrations. These bear the names *quarks*, *leptons*, and *field bosons*. In each category there are quite a few. Now we may contemplate this wonder of wonders. The hardy tangible stuff of the material universe emerges out of infinitesimally small punctual mass concentrations, not unlike a canvas by Georges Seurat on which tiny dabs create magnificent sceneries.

How quarks and leptons and field particles act and interact determines the nature of perceived reality. Those ultimate bricks of *subnature* are responsible for the way the world behaves on our scale and on any. They are the ultimate puppeteers, as it were, the most fundamental of all fundamental particles, for it is to them that physics traces today every known aspect of the physical world[18].

[18] All this is part of the so-called *Standard Model* which will be discussed in a later article. It should be noted here that for a more complete understanding we need to add the notion of *emergence* to this *reductionist* view.

This is a most astounding statement that physics makes. It says, in effect, that every bit of observed event in the phenomenal world, be it tides in oceans, explosions in supernovas, orbits of planets, snowflakes in winter, or sands in the Sahara, or whatever, every single thing and event of perceived reality can be accounted for in terms of a handful of different entities which barely occupy any space at all, for that is what *point-like concentration* means!

It cannot be denied that this is a great discovery, a profound secret, a final answer, something of ultimate revelatory significance. Yet, the irony of human civilization is that, like the luxurious life of jet setters, it is the talk and truth of but a privileged few: a few hundred thousand humans maybe of a population of six billion and more. The rest of the race may have heard of quarks or leptons in some TV specials or write-ups in popular magazines, but they care little for all this, if only because it does not touch them in any significant way. Even who know of this at a superficial level keep clamoring about the limitations of science in contrast to the science of their ancient ancestors.

Transformation of Matter: ***When matter transforms, old molecules give place to new.***

When a log burns, wood turns to smoke and ash. A piece of metal rusts, seedlings grow to plants, gunpowder explodes and food is digested: these too are processes in which one kind of matter changes to others. All these are instances of chemical transformation. Substances may retain their pure existence for long periods. But they also can, and often do, undergo changes in kind, as in the examples cited above. Many of these changes occur naturally in the physical world, and a great many are also brought about by human intervention.

Chemical transformations are instigated by heat or light or electricity or some other form of energy. Their net effect is to change matter from one kind into another. What is happening is change at a basic level, since substances are determined by the content and configuration of their atomic essence. Chemical reactions imply the splitting of old molecules and the forming of new ones, the switching of partners by atoms to dance with other ones, as it were.

Material transformations are occurring unceasingly in the world. When a piece of paper yellows, and acid turns to salt, when the green of summer leaves turns to the golden autumnal glory, silent chemical reactions are at play. Chemical reactions keep dynamic interchanges among the molecules in the world. They are essential for our biological survival for millions of them are continuously at work in our bodies, breaking up and making up molecules, utilizing oxygen and fortifying blood, for the throb of life depends on complex biochemistry.

Modern science has unraveled how countless reactions come about. Human ingenuity contrives chemical reactions of interest and utility for us. This knowledge and skill sustain the giant industries that serve and support a thousand human desires, provide jobs for millions, and incidentally pollute the environment in which we live.

Transmutation: ***When matter transmutes, one element changes into another.***

In former times, some transformations used to be reported which were often naive or deceptive. In the more magical phases of human history, clever individuals claimed they could change lead into silver and copper into gold. When it was superficially successful (i.e., satisfactory to an eager client and went undetected) it could make the practitioner rich and respected. This was magic-mongering *par excellence*, based, it was claimed, on occult skills or spiritual prowess. It persists to this day when god-men produce tangible stuff out of thin air[19]. The transformation of one element into another is called transmutation. But the rosy promises of an alchemy that transmuted base metals to noble ones vanished with the pre-scientific past, though some present-day adherents to defunct views still insist this to be a possibility.

In a peculiar way, the hopes of alchemists are not unrealizable. Today, thanks to an understanding of subatomic (nuclear) physics, physicists bring about transmutations, not in simplistic conversions to covetable metals, but in matter when atomic numbers change in nuclear reactions.

States of Matter: ***Matter transforms non-chemically also.***

Sand and rocks, soil and vegetation, metals and minerals, oil and water are splashed all over our planet. There is also the invisible layer of air which is carried along by our planet in its cruise around the sun. As noted earlier, all matter we know here on earth is either sturdy as solid, flowing as liquid, or tenuous as gas. These are ordinarily observed states of matter. Matter in each of these states has specific properties in regards to its ability to stay put where placed, to run and flow wherever it can, or to expand itself into all available space. As we raise the temperature of a solid chunk, it becomes tender, and eventually melts into the liquid state. When the temperature of a liquid is steadily increased, there comes a point when it begins to vaporize. This phenomenon is readily observed when ice turns to water, and water into steam.

Ultimately, the solidity or fluidity of matter is a reflection of how tightly bound its ultimate constituents are. If atoms and molecules are held together in tight holds, they may at best shiver about their fixed position, like the branches of trees in breeze or wind, but do not break away from their mutual hold. As we heat the solid, we are feeding in more and more energy: it is as

[19] Alchemy has a rich and long history, and is still popular in many parts of the world. In India it was part of classical Ayurveda and was practiced by the Tamil Siddhars and Tantriks, among others. But its practices, let alone assumptions and theories, are not taken seriously by modern chemists anywhere in the world.

if the breeze turns into a more powerful wind, and then the strong hold is weakened to a rope-like link, with far greater freedom for the molecules to drift. Thus we get the liquid phase. And finally, at sufficiently high temperatures, even the weak links are broken off: every molecule becomes utterly independent of every other, buzzing away in all directions, bouncing off here and there from the atoms and molecules it encounters until a hard wall pushes it back into the container wherein it begins to meander every which way once again[20].

Depending on their intrinsic properties, substances are solid, liquid or gaseous at a given temperature. Most elements are solid or gas at the ordinary terrestrial temperatures. Dark red bromine and silvery mercury happen to be the only elements that are ordinarily liquid.

Plasma: ***There is also a fourth state of matter.***

Think of what will happen if a gas were heated to ever increasing temperatures. At the core of matter are atoms which consist of electrically charged nuclei around which are whirling yet smaller charged entities called electrons. At enormously high temperatures the very atoms of which matter is made up will be stripped of their orbiting electrons. Matter will be turned to nuclei in stark nudity, becoming an insufferably hot concentration of mass, gory like a creature that has been skinned, impossible to touch or even be placed in a container, for at its extraordinarily high temperature it will vaporize all that comes to its vicinity.

This is what physics has uncovered: If the temperature of a substance reaches to extraordinary heights – of the order of a few million degrees – then matter is transformed to still another phase. We call matter in this state *plasma*[21]. Pure plasma is unimaginably hot matter. Where can Nature hold such super-hot substance save in the wilderness of empty space, far away from ordinary material concentrations? All those twinkling stars, our sun included, whose temperatures are fantastically high, have matter in the plasma state.

One would have thought that plasma was more the exception than the rule. But no, as with geocentricity, Nature has fooled us again! Much of the matter in the universe – at least of the kind we have observed thus far – is more plasma than plain, for the stars are where the action really is. It is in the bowels of stars that most matter is concentrated. Stars are massive beyond comprehension. Interstellar dust, planets and other rocky blobs are anomalies. These are cooler states of matter where, sometimes, life can evolve and flowers can blossom.

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[20] William Crookes in England observed electrical discharges in gas in the 1890s. This was the first laboratory generated plasma. The term plasma for this was coined by the American chemist Irving Langmuir in 1928.

[21] Stephen O Dean, The Plasma Touch, in *The World & I*, June 1996.

But the scientific spirit will not be content with the mere knowledge that there is plasma out there in those distant pockets in the universe. Why not create it right here on earth. We get fleeting glimpses of plasma when a lightning flashes and when the northern lights illumine the sky, for these are also manifestations of ordinary matter turned into picturesque plasma. Human ingenuity has succeeded in making plasma of the stellar variety also, for that is what obtains in the heart of a hydrogen bomb when set aflame, and in laboratories that explore how one may tap nuclear fusion for human needs. Those horrible hydrogen bombs are of course awesome, threatening, and wrought with potential disaster. But, in the context of physics and human accomplishment, we may look upon one of their explosions as a momentary mini-star right here on our own earth! Never before in all of cosmic history – as far as we know – has nuclear fusion occurred in a region that is not in the entrails of a star. No small achievement, this!

We have concocted weaker plasmas for more imminent use: these are gases from whose atoms, not all, but just a couple of electrons have been stripped. These are so-called ionized gases. They were already known in the 19th century, long before they were recognized as such. But in the last decades of the 20th century, they began to play a major role in a variety of industries: aerospace, biomedical, steel, and electronics. Sulfur plasma lamps are immensely more powerful (provide far more illumination) than high intensity ordinary light bulbs. As Stephen O Dean noted[21], "precision plasma-processing is quietly underpinning much of the current phase of a new technological revolution that is slowly occurring".

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