A. Vibert Douglas "From Atoms to Stars"

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Salve! Frater!
Te amo.
A.V.D.

FROM ATOMS TO STARS

BY A. VIBERT DOUGLAS

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Throughout the ages intellectual progress has been due to three attributes of mankind — a deeply implanted, insatiable curiosity; a far-reaching, unrestrainable, unfetterable imagination; and an undaunted faith that there is order in the universe, an underlying harmony in nature. Dean Inge, who is one of the few distinguished men of letters to possess a keen and sympathetic understanding of the aims, ideals, and spirit of scientific inquiry, has written these words: 'The dramatic fancy which creates myths is the raw material of both poetry and science. Curiosity, imagination, and faith — these are the qualities of mind which have led the natural philosophers of every age to search patiently amid the phenomena of nature that they might perchance discover the reality behind and beneath the appearance of things.

To every investigator there come moments when his thought is baffled, when the limits of experimental possibility seem to have been reached and he faces a barrier which defies his curiosity. Then it is that imagination, like a glorious greyhound, comes bounding along, leaps the barrier, and a vision is flashed before the mind — a vision no doubt that is partly false, but a vision that may be partly true. It stirs up new ideas in the thoughts of the investigator, it fires him with a fresh enthusiasm and his curiosity spurs him on to further endeavors. Thus is brought about the gradual growth of knowledge.

I

The greyhound imagination of the Greeks pictured the atom, the ultimate particle of matter, smaller than anything that human eye can see. Almost three hundred years ago, the greyhound imagination of Pascal saw a vision of what was within the atom: 'Consider the last least object [the atom] at which he [the scientist] can arrive. Perhaps he will think that it is the limit of littleness in nature. But I will show him within this a new abyss. I will paint for him not only the visible universe, but all the immensity of nature that one can conceive within the bounds of this epitome of an atom. He may see an infinity of universes, each with its firmament, its planets, its earth, in the same proportions as in the visible world.'

In the light of the revelations of the last twenty-five years, Pascal's vision is indeed remarkable. Overdrawn though it undoubtedly is in some respects, there is more than a germ of truth within it, and the last phrase in particular is strikingly prophetic. We know to-day the proton and the electron and how in the hydrogen atom the latter revolves about the more ponderable former, very much as a planet about the sun. We know, too, that the heavier elements are composed of atoms having a nucleus made up of some compact aggregation of protons and electrons, while outer electrons in orbits like planets and comets revolve about this massive centre.

To-day the greyhound imagination of a Rutherford is leaping the barrier of the complex atomic nucleus, while the picks and spades and battering-rams of his associates are opening for us a breach into the very citadel of the atom. Here we are dealing with the limit of smallness to which the human mind has attained.

But the human mind goes outward to the immensities as well as inward to the atom. Here, too, the imagination has played its part and astronomers have done what Ulysses longed to do —'To sail beyond the sunset and the baths of all the western stars.' Young men have seen visions and old men have dreamed dreams; these flights of the imagination have paved the way for the advance of knowledge. These visions and dreams are among the highest peaks of human achievement.

Man has looked out into space beyond the sun and solar system of planets, satellites, asteroids, comets, and meteors, out beyond the six thousand stars visible to the naked eye, beyond the thousands of stars revealed to the eye by means of a telescope, beyond the millions of stars recorded photographically and estimated statistically — and what does he see? He sees spiral nebulæ, clusters of one hundred million stars, island galaxies to the number of many thousands — possibly there are many millions. And of these myriad stars each one is a radiant sun, a sphere of inconceivably hot, glowing gas. The majority are as large as or larger than our sun, and their average distances are such that if one star were represented by a golf ball the next star would be another golf ball, or perhaps a football, or a small balloon, some thousand miles away.

II

To gain some idea of these astronomical distances let us imagine that the Golden Arrow, whose recent record of 231 miles per hour astonished the world, should travel around the earth at the equator, contenting itself with a speed of 200 miles per hour. It would complete the journey in five days. At the same speed it would cover the distance from earth to moon in fifty days. It would arrive at the sun in fifty-three years. Neptune, the outpost planet of our solar system, would not be reached until fifteen hundred years had elapsed, and then through interstellar space the Golden Arrow would speed on and on for thirteen million years ere it would reach a neighboring star. After ninety thousand million years, when it has passed through all the stars of the Milky Way and arrived at the confines of our galaxy, — like a traveler who comes to the border town of his own country, — in a sense the journey has just commenced, the exploration of the universe is about to begin.

No doubt Shakespeare thought that he was taxing the imagination of his audience to the utmost when he made Puck, the messenger of the fairies, assert his capacity for speed thus: 'I'll put a girdle round about the earth in forty minutes.' Our generation would not tolerate a fairy who could do no better than that! Have we not the radio wave that will encircle the earth in one seventh of a second?

Let us then desert the Golden Arrow for a golden sunbeam, that swiftest known messenger, the electromagnetic radiation which travels through space at 186,000 miles per second. A sunbeam comes down to the surface of the earth, hits a smooth shiny object, and is reflected outward again. At the moment of rebound, vault into the saddle, and away you go to explore the universe. In one and one-third seconds you have passed the moon, in eight and four-tenths minutes the sun is left behind, and after four years the first

neighboring star looms large ahead. Thereafter, every four or five years will bring you near to some great sun, or perhaps to some binary system where two great stars revolve about one another. Less often, but nevertheless not infrequently, it will be a multiple system of three or four or more suns revolving about one another in pairs, and the pairs about the common gravitational centre of their group. Undoubtedly there will be an occasional star that you will find, as you approach closely, to be surrounded, like our own sun, by a family of planets, of comets, and of meteoric swarms. What may you not see as your sunbeam carries you close to some of these planets? Our imagination loses itself in speculative wonderings.

But you will have abundant time to ponder on the sights and the marvels of any one group of stars or solar systems ere you reach another, — several years of meditation, — unless perchance your course leads you into a dense nebulous region of interstellar space where your sunbeam is buffeted this way and that, so that it is no easy matter to avoid disaster. An oxygen atom here, a nitrogen atom there, a meteoric fragment just beyond, and your sunbeam just misses the one, collides with the other, losing some of its energy, is buffeted by the third, and swerves off obliquely. Thus on and on from one excitement to another, year in and year out, until at long last the vast nebula is traversed and you emerge into less crowded regions of space.

One hundred thousand years of journeying thus will bring you to the outermost limits of the Milky Way, the frontiers of our galaxy — and what then? It is then, and then only, as your sunbeam begins its million-year journey across cloudless, starless space, that your exploration of the universe may be said to have really begun. Looking backward upon our galaxy, you see it as a mighty aggregation of a thousand million stars not distributed evenly in a spherical volume of space, but in a volume flattened above and below into a disc or lens-shaped configuration. Looking around you in all other directions, you see what seems to be a vast void with here and there — incredibly far off — a faint, faint, hazy light. Let your sunbeam carry you toward the brightest of these phantom lights. As the centuries roll by, the great galaxy behind you recedes into the background until it too is merely a faint phantom patch of fuzzy light. More centuries come and go, and the phantom light before you grows more real, its true nature dawns upon you — it is another galaxy of many million stars.

Each one of the far-away phantom lights, and there are myriads of them, is a star galaxy, and we do not wonder that the spirit of the man in Richter's legend grew faint at the immensity of space and asked in tones of awe akin to dismay, 'End is there none to the universe of God?' 'And,' continues Richter, 'all the stars echoed the question with amazement . . . and this echo found no answer.'

III

The human mind roves through the universe exploring its mysteries from one end of the scale to the other, from the inconceivably small things — the electron, the proton, the atom — to the incomprehensibly vast things — the stars and star galaxies. Where is man in this scale of magnitudes? Man as a physical body, a quantity of matter, — as distinct from man as a mental and spiritual entity, — must be somewhere between these two extremes, the atom and the star. In ancient mythology, Astræa, the goddess of justice, is represented as a figure of commanding dignity holding in outstretched hand the scales or balance of equity. Imagine the goddess undertaking to weigh out the energy content of different material objects in the universe. In one pan she places an average man and from a cornucopia she pours individual atoms into the other pan. How many atoms will be required to bring about a true and just balance? A thousand million million million million! Next she removes the atoms from the pan and in their places she puts one average star. Now the other pan is much too light, and so she puts more and more and yet more men into it until there are ten thousand million million million million men, when the balance is reached. Here, then, is man's place in the avoirdupois scale of the universe — almost but not quite halfway between atom and star. It is from this midway point that man, because of his mental and spiritual endowments, can survey the smaller things of nature on the one hand and the greater things upon the other hand with an ever-increasing curiosity and comprehension.

Let us suppose that two young investigators, filled with the curiosity, imagination, and faith of the scientific worker, come to Dame Nature and say: We wish to give our lives to scientific research, 'to follow knowledge like a sinking star beyond the utmost bound of human thought' — what shall we do? To one Dame Nature replies: Take thou the atom. To the other she says: Take thou the star. Perhaps you think, as they do, that their paths will never cross — the one in his laboratory delving into the profundities of things so small no microscope will reveal them, the other in his observatory photographing a vast galaxy of myriad giant stars. You can imagine that possibly they will grow discontented with their lots, and, with that strange perversity of human nature, the one will come to Dame Nature and say: You told me to study atoms, but I should like to study stars! And the other returns and says: You told me to study the stars, but I want to study atoms! And Dame Nature smiles quietly as she replies: Yes, I told you to study the atom; return to your laboratory, bend all your energy to the task, and some day you will find that the walls of your laboratory are expanding and expanding until they include — the stars. And to the other young investigator she answers: Yes, I told you to study stars; return to your telescope, your spectroscope, and your measuring instruments, and lo! some day you will awaken to find that you are really studying atoms.

This is not merely a parable — it is the actual truth; and the remaining portion of this article will have failed in its purpose if it does not carry conviction that this is the case.

IV

The physicist and the astronomer have much in common and of necessity the latter owes a very great debt to the former. Since the astronomer can know nothing of the nature of the stars save what he can find written in the starlight, it is natural that he should early ask, — and he has been repeating the question at intervals ever since, — 'What is light?' At different times the physicist has made somewhat different answers. To-day, if he be in a humorous mood, his answer may be along these lines. He picks up a piece of red chalk and draws a sinuous curve to represent a wave. Above this he draws the figure of a runner striding from crest to crest with a small pack sack on his back. With orange chalk he draws another wave of slightly shorter wave length, — that is to say, the distance from crest to crest is less, — and on this is drawn an orange runner with shorter legs, since his stride is less, but carrying

a larger pack sack. Then a yellow wave with a yellow runner, a green wave and a green runner, and similarly for blue, for indigo, for violet, until he has all the spectrum colors represented; but each successive wave is shorter from crest to crest, the corresponding messenger has shorter and shorter legs, and the pack sacks are larger and larger. Can you picture the Marathon Race of the Light Rays? Ninety-three million miles away, at an instant *Go!* some atoms in the sun rearrange their orbital electrons, thus liberating some energy; out spring the little messengers with the spare energy in pack sacks on their backs and race away toward the earth. Who will win the race? Surely not the little violet runner with the very short legs and the very big load? Perhaps you would stake your all on the long-legged red runner with the small pack sack? But here is the remarkable thing: for eight and a fraction minutes they race abreast and at the finish there is no final sprint — they all break the tape together. It is a dead heat.

We might watch the runners in a longer race, a race from the Andromeda Galaxy to the earth, but if so we must have great patience, for when the runners leave that distant star cluster their little legs will flash up and down, backward and forward, for a million years before the finishing line is approached. Again it is a dead heat, and if the goal be the retina of your eye turned upward toward the constellation of Andromeda, at a certain moment the runners will all arrive and lay down their burdens. Each pack sack of energy upon your retina causes an electrical current to run swiftly up an optic nerve to the brain, and your brain informs you that at that moment you are seeing the Andromeda Galaxy. Thus the physicist, with some help from the physiologist, explains the sensation of 'seeing,' but he utters a warning regarding the interpretation of the sensation. When you say that you are seeing Andromeda Galaxy, you are seeing it as it was one million years ago, not as it is to-day — exactly what it is like to-day will only be known on the earth a million years hence when the messengers now setting out from that far-off cluster have completed their long race.

But curiosity overcomes the circumspection of the physicist and provokes him to ask what that star cluster does look like to-day. To which question the astronomer makes reply that in all probability it looks very much as it did a million years ago, for in the age of a star or a star cluster a million years is no more than is one second of time in the life of an average man. It will be somewhat more spread out with less nebulous matter uncondensed into stars and it will be somewhat turned around, for the astronomer knows that this vast galaxy is slowly and majestically rotating with a period of some seventeen million years.

The picture of light which the physicist gives us is thus a dual one. We must think of a continuous undulating influence emanating from a radiating body if we are to explain reflection, refraction, diffraction, and interference of light — this the physicist calls his Electromagnetic Wave Theory of light. But if we would explain the mechanism of the emission of light by an atom, the absorption of light, photographic and photo-electric phenomena, we must fix our thoughts on the little runners and their pack sacks of energy — this the physicist refers to as the Quantum Theory of light. The essence of this theory is that to the runner associated with each different wave there is assigned a pack sack of definite size, and no runner will ever carry a pack sack either heavier or lighter than his own just, meet, and proper load, nor will he ever give up a portion of his load of energy — 'Take the whole or none' is his ultimatum to the atoms he encounters. An atom can accept a pack sack containing more energy than it can store, but after taking what it needs it must reradiate the remainder as a ray of longer wave length — in other words, a new messenger goes off whose longer legs and slower stride are just suited to the lesser load of energy.

This picture is not limited to visible light. There are invisible waves, the infra-red, the heat, and the Hertzian or radio waves, each longer in wave length than the previous one and the corresponding quantum of energy smaller. So, also, there are the unseen ultra-violet rays, the X-rays, gamma rays, and the cosmic rays of shortest-known wave length. Quantum theory associates a messenger with each of these also, and the pack sacks increase steadily in capacity as the wave lengths diminish.

The astronomer ponders often, long, and deeply over the nature of light and the individual characteristics of the light from the sun and the stars. Gradually it has dawned upon him that with the aid of the physicist he can unravel many of the riddles of the stars. What are the stars made of? The physicist produces a table of the distinctive radiations emitted by the different kinds of atoms known on the earth. It is the Rosetta stone that makes possible the deciphering of the message in the starlight, and by its aid the astronomer finds that the same elements that build the earth build the sun and all the stars. How hot are the stars? Again the physicist rises to the occasion and shows how the color of a hot body changes as its temperature increases. This method of estimating temperatures by the color of the light radiated by the glowing body is in common use by metallurgists, who speak of a mass of molten metal being faint red, cherry, bright red, salmon, orange, lemon, light yellow, and so on as the temperature changes from about 900° F. to about 2000° F. The coolest stars are not much hotter than the hottest metal obtainable in a furnace, and so the astronomer can extend the color scale farther up the spectrum to the hottest-known blue stars having surface temperatures of 20,000° F. or more.

How fast are the stars moving toward or from us? Once more the astronomer appeals to the physicist, and once more a reply is given which enables him to interpret the minute changes in positions of the spectrum lines as indicative of the velocities of the stars.

V

Astronomy owes an immense debt to physics, but the indebtedness is not entirely one-sided. The astronomer discovered in the sunlight evidence for the existence of an element unknown on the earth — helium. Physicists and chemists were at once on the alert to find it, and, when at length it had been found, helium proved to be of crucial importance in theoretical investigations in atomic structure, in radioactivity, and in spectroscopy. In fact, no atom save only the hydrogen atom has been more closely studied by physicists. The practical value of helium is well known on account of its being the best nonexplosive gas for lighter-than-air machines.

Many examples might be given of the ways in which the astronomer can throw light upon problems which at one time or another have baffled the physicist. Sometimes astronomy provides the physicist with startling new ideas of the properties of matter — properties undreamed of in the laboratory

but clearly exhibited in the stars, where the conditions of high temperature far transcend anything reproducible on the earth. What physicist ten years ago would have even contemplated matter so compacted together that one cubic inch of it would weigh a ton? Yet to-day the astronomer points directly to the faint companion star of Sirius and says, 'There it is, and here is the spectroscopic evidence which proves that this is so. . . .'

For many reasons the physicist is interested to know how much energy is required to knock an electron completely out of an atom, or, as he expresses it, to ionize an atom. For many of the elements he has been unable in his laboratory to measure this directly, and so the astronomer has come to the rescue. Indian and English physicists have evolved the theory underlying the problem, and astronomers at Harvard have asked stars of various temperatures to tell their ionization stories, with the result that carbon, silicon, scandium, iron, and other elements radiating in the stars provided some of the answers. At McGill University, instead of asking many stars of differing temperatures, one star whose temperature changes periodically was asked the question: What are the ionization potentials of iron, of vanadium, of yttrium, and of lanthanum? And in the starlight the answers were found.

An astronomer and a physicist were one day walking over an English meadowland where the skylarks were continually rising from the grass, soaring upward and upward, singing their glorious song of confident aspiration, higher and higher into the upper air — and then quite suddenly, like a falling stone, each skylark returned to the ground. After watching them for some time the physicist threw himself down on the grassy slope and said, 'I wonder how long, on the average, those birds stay up in the sky.' So they began to time them. One was up ten seconds, another eight, a third nine, and so on — nine, seven, twelve, nine, ten, nine, nine, eight, nine, eleven. . . .

'Well,' said the astronomer, 'I think we have discovered something about skylarks — let us write a book on Birds, beginning thus: "The English Skylark is a little bird that flies up out of a meadow singing a beautiful song and staying up in the sky, on the average, nine seconds before he returns rapidly to the earth."'

But the physicist did not laugh. He was deep in thought. At length he turned to the astronomer and said, 'Do you know, there is a problem that has been worrying me that is just like these skylarks! We know a good deal about calcium — one electron can be dislodged, leaving the atom with nineteen electrons going about the nucleus in orbits. When the atom absorbs a little energy, the outermost of these electrons behaves just like a skylark — it flies up to a higher orbit; true, it does not sing a beautiful song, but it does something else: it emits the loveliest little ripple of violet light — and then, suddenly, down it comes again to its ground level. My question is this: How long, on the average, does the skylarking electron remain up in its higher orbit?'

'The answer to your question is one hundred millionth of a second,' replied the astronomer. 'The sunlight tells us that, but it is a long story. Here it is in brief outline. Astronomers were perplexed because calcium atoms are abundant farther out in the atmosphere of the sun than even the lightest of all gases, hydrogen. Photographs of the outer atmosphere or chromosphere of the sun taken at the time of a total eclipse show the red and the yellow light from hydrogen atoms as far out as four thousand to six thousand miles from the sun's surface, but the violet light from ionized calcium atoms proves that those atoms are out as far as nine thousand miles from the photosphere. These atoms can only stay out there if the sun's gravitational attraction, which is pulling them inward continually, is counterbalanced by the outward impulses given to the atom every time it absorbs the energy which sends its skylarking electron to a higher orbit. Thus the number of these impulses will depend upon the rate at which the electron returns to its lower orbit ready to receive another impulse upward.'

One hundred millionth of a second! To us this may seem an inconceivably brief interval, but to the electron it provides ample time for a million revolutions about the nucleus. Anyone can measure the passage of time to one fifth of a second with a stop watch, the physicist with his oscillograph measures intervals of one millionth of a second, but the timekeeping of the skylarking electrons transcends our powers of comprehension. At the other extreme is the astronomer's estimate of the age of a star, equally beyond our realization — ten million million years.

It is a solemn thought that no man liveth unto himself. It is equally true that no star, no atom, no electron, no ripple of radiant energy, exists unto itself. All the problems of the physical universe are inextricably bound up with one another in the relations of space and time.

You cannot solve the riddles of the stars without invoking the aid of the atom, nor can you fully comprehend the atom without the aid of the stars. On the uplifting swings of imagination the astrophysicist roams the universe from atom to atom, from star to star, from star to atom, from atom to star. Impelled by curiosity regarding the natural universe, encouraged by the evidences for his faith in the reality of cosmic harmony, he presses on and on — ~~a sweet and a fitting thing it is to toil for the Truth.~~ Dulce et decorum est pro Veritate laborare.