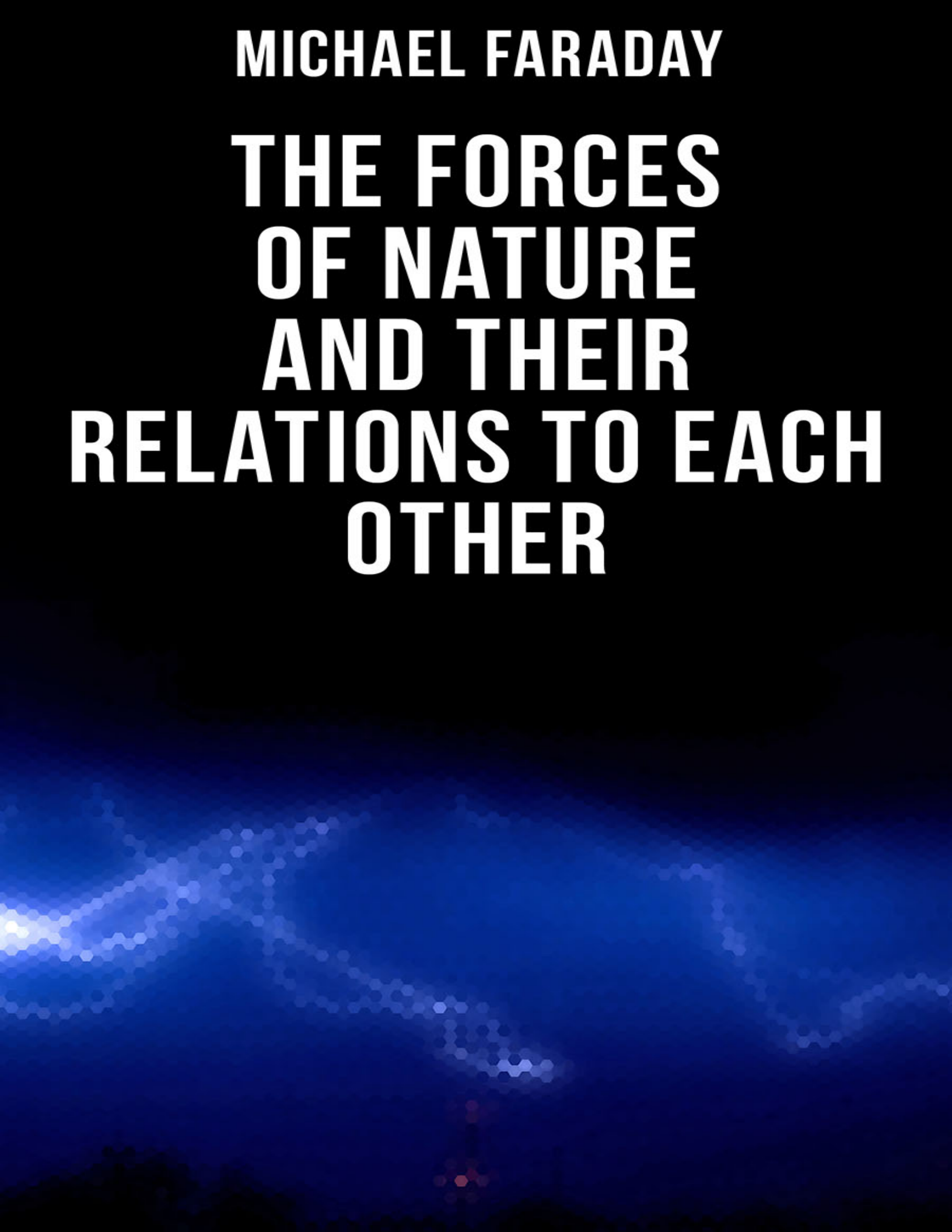
MICHAEL FARADAY

THE FORCES OF NATURE AND THEIR RELATIONS TO EACH OTHER



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The Forces of Nature and their Relations to Each Other

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PREFACE.

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Which was first, Matter or Force? If we think on this question, we shall find that we are unable to conceive of matter without force, or of force without matter. When God created the elements of which the earth is composed, He created certain wondrous forces, which are set free, and become evident when matter acts on matter. All these forces, with many differences, have much in common, and if one is set free, it will immediately endeavour to free its companions. Thus, heat will enable us to eliminate light, electricity, magnetism, and chemical action; chemical action will educe light, electricity, and heat. In this way we find that all the forces in nature tend to form mutually dependent systems; and as the motion of one star affects another, so force in action liberates and renders evident forces previously tranquil.

We say tranquil, and yet the word is almost without meaning in the Cosmos.—Where do we find tranquillity? The sea, the seat of animal, vegetable, and mineral changes, is at war with the earth, and the air lends itself to the strife. The globe, the scene of perpetual intestine change, is, as a mass, acting on, and acted on, by the other planets of our system, and the very system itself is changing its place in space, under the influence of a known force springing from an unknown centre.

For many years the English public had the privilege of listening to the discourses and speculations of Professor Faraday, at the Royal Institution, on Matter and Forces; and it is not too much to say that no lecturer on Physical Science, since the time of Sir Humphrey Davy, was ever

listened to with more delight. The pleasure which all derived from the expositions of Faraday was of a somewhat different kind from that produced by any other philosopher whose lectures we have attended. It was partially derived from his extreme dexterity as an operator: with him we had no chance of apologies for an unsuccessful experiment—no hanging fire in the midst of a series of brilliant demonstrations, producing that depressing tendency akin to the pain felt by an audience at a false note from a vocalist. All was a sparkling stream of eloquence and experimental illustration. We would have defied a chemist loving his science, no matter how often he might himself have repeated an experiment, to feel uninterested when seeing it done by Faraday.

The present publication presents one or two points of interest. In the first place, the Lectures were especially intended for young persons, and are therefore as free as possible from technicalities; and in the second place, they are printed as they were spoken, *verbatim et literatim*. A careful and skilful reporter took them down; and the manuscript, as deciphered from his notes, was subsequently most carefully corrected by the Editor as regards any scientific points which were not clear to the short-hand writer; hence all that is different arises solely from the impossibility, alas! of conveying the manner as well as the matter of the Lecturer.

May the readers of these Lectures derive one-tenth of the pleasure and instruction from their perusal which they gave to those who had the happiness of hearing them!

W. CROOKES.

THE
VARIOUS FORCES OF NATURE.

LECTURE I.
THE FORCE OF GRAVITATION.

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It grieves me much to think that I may have been a cause of disturbance in your Christmas arrangements[1], for nothing is more satisfactory to my mind than to perform what I undertake; but such things are not always left in our own power, and we must submit to circumstances as they are appointed. I will to-day do my best, and will ask you to bear with me if I am unable to give more than a few words; and as a substitute, I will endeavour to make the *illustrations* of the sense I try to express as full as possible; and if we find by the end of this lecture that we may be justified in continuing them, thinking that next week our power shall be greater—why, then, with submission to you, we will take such course as you may think fit—either to go on, or discontinue them; and although I now feel much weakened by the pressure of illness (a mere cold) upon me, both in facility of expression and clearness of thought, I shall here claim, as I always have done on these occasions, the right of addressing myself to the younger members of the audience. And for this purpose, therefore, unfitted as it may seem for an elderly infirm man to do so, I will return to second childhood and become, as it were, young again amongst the young.

Let us now consider, for a little while, how wonderfully we stand upon this world. Here it is we are born, bred, and live, and yet we view these things with an almost entire absence of wonder to ourselves respecting the way in which all this happens. So small, indeed, is our wonder, that we are never taken by surprise; and I do think that, to a young person of

ten, fifteen, or twenty years of age, perhaps the first sight of a cataract or a mountain would occasion him more surprise than he had ever felt concerning the means of his own existence—how he came here; how he lives; by what means he stands upright; and through what means he moves about from place to place. Hence, we come into this world, we live, and depart from it, without our thoughts being called specifically to consider how all this takes place; and were it not for the exertions of some few inquiring minds, who have looked *into* these things and ascertained the very beautiful laws and conditions by which we *do* live and stand upon the earth, we should hardly be aware that there was anything wonderful in it. These inquiries, which have occupied philosophers from the earliest days, when they first began to find out the laws by which we grow, and exist, and enjoy ourselves, up to the present time, have shewn us that all this was effected in consequence of the existence of certain *forces*, or *abilities* to do things, or *powers*, that are so common that nothing can be more so; for nothing is commoner than the wonderful powers by which we are enabled to stand upright—they are essential to our existence every moment.

It is my purpose to-day to make you acquainted with some of these powers; not the vital ones, but some of the more elementary, and, what we call, *physical* powers: and, in the outset, what can I do to bring to your minds a notion of neither more nor less than that which I mean by the word *power*, or *force*? Suppose I take this sheet of paper, and place it upright on one edge, resting against a support before me (as the roughest possible illustration of something to be disturbed), and suppose I then pull this piece of string which is attached to it. I pull the paper over. I have therefore brought into use a *power* of doing so—the *power* of my hand carried on through this string in a way which is very remarkable when we come to analyse it; and it

is by means of these powers conjointly (for there are several powers here employed) that I pull the paper over. Again, if I give it a push upon the other side, I bring into play a *power*, but a very different exertion of power from the former; or, if I take now this bit of shell-lac [a stick of shell-lac about 12 inches long and 1½ in diameter] and rub it with flannel, and hold it an inch or so in front of the upper part of this upright sheet, the paper is immediately moved towards the shell-lac, and by now drawing the latter away, the paper falls over without having been touched by anything. You see—in the first illustration I produced an effect than which nothing could be commoner—I pull it over now, not by means of that string or the pull of my hand, but by some action in the shell-lac. The shell-lac, therefore, has a *power* wherewith it acts upon the sheet of paper; and as an illustration of the exercise of another kind of power, I might use gunpowder with which to throw it over.

Now, I want you to endeavour to comprehend that when I am speaking of a *power* or *force*, I am speaking of that which I used just now to pull over this piece of paper. I will not embarrass you at present with the *name* of that power, but it is clear there was a *something* in the shell-lac which acted by attraction, and pulled the paper over; this, then, is one of those things which we call *power*, or *force*; and you will now be able to recognise it as such in whatever form I shew it to you. We are not to suppose that there are so very many different powers; on the contrary, it is wonderful to think how few are the powers by which all the phenomena of nature are governed. There is an illustration of another kind of power in that lamp; *there* is a power of heat—a power of doing something, but not the same power as that which pulled the paper over: and so, by degrees, we find that there are certain other powers (not many) in the various bodies around us. And thus, beginning with the simplest experiments of pushing and pulling, I shall

gradually proceed to distinguish these powers one from the other, and compare the way in which they combine together. This world upon which we stand (and we have not much need to travel out of the world for illustrations of our subject; but the mind of man is not confined like the matter of his body, and thus he may and does travel outwards; for wherever his sight can pierce, there his observations can penetrate) is pretty nearly a round globe, having its surface disposed in a manner of which this terrestrial globe by my side is a rough model; so much is land and so much is water, and by looking at it here we see in a sort of map or picture how the world is formed upon its surface. Then, when we come to examine further, I refer you to this sectional diagram of the geological strata of the earth, in which there is a more elaborate view of what is beneath the surface of our globe. And when we come to dig into or examine it (as man does for his own instruction and advantage, in a variety of ways), we see that it is made up of different kinds of matter, subject to a very few powers, and all disposed in this strange and wonderful way, which gives to man a history—and such a history—as to what there is in those veins, in those rocks, the ores, the water springs, the atmosphere around, and all varieties of material substances, held together by means of *forces* in one great mass, 8,000 miles in diameter, that the mind is overwhelmed in contemplation of the wonderful history related by these strata (some of which are fine and thin like sheets of paper)—all formed in succession by the forces of which I have spoken.

I now shall try to help your attention to what I may say by directing, to-day, our thoughts to one kind of power. You see what I mean by the term *matter*—any of these things that I can lay hold of with the hand, or in a bag (for I may take hold of the air by enclosing it in a bag)—they are all portions of matter with which we have to deal at present, generally

or particularly, as I may require to illustrate my subject. Here is the sort of matter which we call *water*—it is *there* ice [pointing to a block of ice upon the table], *there* water [pointing to the water boiling in a flask], *here* vapour—you see it issuing out from the top [of the flask]. Do not suppose that that ice and that water are two entirely different things, or that the steam rising in bubbles and ascending in vapour *there* is absolutely different from the fluid water. It may be different in some particulars, having reference to the *amounts* of power which it contains; but it is the same, nevertheless, as the great ocean of water around our globe, and I employ it here for the sake of illustration, because if we look into it we shall find that it supplies us with examples of all the powers to which I shall have to refer. For instance, here is water—it is heavy; but let us examine it with regard to the *amount* of its heaviness, or its gravity. I have before me a little glass vessel and scales [nearly equipoised scales, one of which contained a half-pint glass vessel], and the glass vessel is at present the lighter of the two; but if I now take some water and pour it in, you see that that side of the scales immediately goes down; that shews you (using common language, which I will not suppose for the present you have hitherto applied very strictly) that it is *heavy*: and if I put this additional weight into the opposite scale, I should not wonder if this vessel would hold water enough to weigh *it* down. [The Lecturer poured more water into the jar, which again went down.] Why do I hold the bottle *above* the vessel to pour the water into it? You will say, because experience has taught me that it is necessary. I do it for a better reason—because it is a law of nature that the water should fall towards the earth, and therefore the very means which I use to cause the water to enter the vessel are those which will carry the whole body of water down. That power is what we call *gravity*, and you see *there* [pointing to the scales] a good deal of water gravitating towards the earth.