works, before we inquire into their make, ſtrike us with the moſt lively ideas of beauty and magnificence.

3. BUT if there be ſo ſtrong a paſſion in contemplative minds for natural philoſophy; all ſuch muſt certainly receive a particular pleaſure in being informed of Sir ISAAC NEWTON's diſcoveries, who alone has been able to make any great advancements in the true courſe leading to natural knowledge: whereas this important ſubject had before been uſually attempted with that negligence, as cannot be reflected on without ſurprize. Excepting a very few, who, by purſuing a more rational method, had gained a little true knowledge in ſome particular parts of nature; the writers in this ſcience had generally treated of it after ſuch a manner, as if they thought, that no degree of certainty was ever to be hoped for. The cuſtom was to frame conjectures; and if upon comparing them with things, there appeared ſome kind of agreement, though very imperfect, it was held ſufficient. Yet at the ſame time nothing leſs was undertaken than intire ſyſtems, and fathoming at once the greateſt depths of nature; as if the ſecret cauſes of natural effects, contrived and framed by infinite wiſdom, could be ſearched out by the ſlighteſt endeavours of our weak underſtandings. Whereas the only method, that can afford us any proſpect of ſucceſs in this difficult work, is to make our enquiries with the utmoſt caution, and by very ſlow degrees. And after our moſt diligent labour, the greateſt part of nature will, no doubt, for ever remain beyond our reach.

4. THIS

4. THIS neglect of the proper means to enlarge our knowledge, joined with the preſumption to attempt, what was quite out of the power of our limited faculties, the Lord BACON judiciouſly obſerves to be the great obſtruction to the progreſs of ſcience [a]. Indeed that excellent perſon was the firſt, who expreſly writ againſt this way of philoſophizing; and he has laid open at large the abſurdity of it in his admirable treatiſe, intitled NOVUM ORGANON SCIENTIARUM; and has there likewiſe deſcribed the true method, which ought to be followed.

5. THERE are, ſaith he, but two methods, that can be taken in the purſuit of natural knowledge. One is to make a haſty tranſition from our firſt and ſlight obſervations on things to general axioms, and then to proceed upon thoſe axioms, as certain and unconteſtable principles, without farther examination. The other method; (which he obſerves to be the only true one, but to his time unattempted;) is to proceed cautiouſly, to advance ſtep by ſtep, reſerving the moſt general principles for the laſt reſult of our inquiries [b]. Concerning the firſt of theſe two methods; where objections, which happen to appear againſt any ſuch axioms taken up in haſte, are evaded by ſome frivolous diſtinction, when the axiom it-ſelf ought rather to be corrected [c]; he affirms, that the united endeavours of all ages cannot make it ſucceſsful; becauſe this original error in the firſt digeſtion of the mind (as he expreſſes himſelf) cannot afterwards be remedied [d]: whereby he would ſignify to us, that if we ſet out in a

[a] Nov. Org. Scient. L. i. Aphoriſm. 9.
[b] Nov. Org. L. 1. Aph. 19.
[c] Ibid. Aph. 25.
[d] Aph. 30. Errores radicales & in prima digeſtione mentis ab excellentia functionum & remediorum ſequentium non curantur.

wrong

wrong way; no diligence or art, we can uſe, while we follow ſo erroneous a courſe, will ever bring us to our deſigned end. And doubtleſs it cannot prove otherwiſe; for in this ſpacious field of nature, if once we forſake the true path, we ſhall immediately loſe our ſelves, and muſt for ever wander with uncertainty.

6. THE impoſſibility of ſucceeding in ſo faulty a method of philoſophizing his Lordſhip endeavours to prove from the many falſe notions and prejudices, to which the mind of man is expoſed [a]. And ſince this judicious writer apprehends, that men are ſo exceeding liable to fall into theſe wrong tracts of thinking, as to incur great danger of being miſled by them, even while they enter on the true courſe in purſuit of nature [b]; I truſt, I ſhall be excuſed, if, by inſiſting a little particularly upon this argument, I endeavour to remove whatever prejudice of this kind, might poſſibly entangle the mind of any of my readers.

7. HIS Lordſhip has reduced theſe prejudices and falſe modes of conception under four diſtinct heads [c].

8. THE firſt head contains ſuch, as we are ſubject to from the very condition of humanity, through the weakneſs both of our ſenſes, and of the faculties of the mind [d]; ſeeing, as this author well obſerves, the ſubtilty of nature far exceeds the greateſt ſubtilty of our ſenſes or acuteſt reaſonings [e]. One

[a] Aph. 38.
[b] Ibid.
[c] Aph. 39.
[d] Aph. 41.
[e] Aph. 10, 24.

of

of the falſe modes of conception, which he mentions under this head, is the forming to our ſelves a fanciful ſimplicity and regularity in natural things. This he illuſtrates by the following inſtances; the conceiving the planets to move in perfect circles; the adding an orb of fire to the other three elements, and the ſuppoſing each of theſe to exceed the other in rarity, juſt in a decuple proportion [a]. And of the ſame nature is the aſſertion of DES CARTES, without any proof, that all things are made up of three kinds of matter only [b]. As alſo this opinion of another philoſopher; that light, in paſſing through different mediums, was refracted, ſo as to proceed by that way, through which it would move more ſpeedily, than through any other [c]. The ſecond erroneous turn of mind, taken notice of by his Lordſhip under this head, is, that all men are in ſome degree prone to a fondneſs for any notions, which they have once imbibed; whereby they often wreſt things to reconcile them to thoſe notions, and neglect the conſideration of whatever will not be brought to an agreement with them; juſt as thoſe do, who are addicted to judicial aſtrology, to the obſervation of dreams, and to ſuch-like ſuperſtitions; who carefully preſerve the memory of every incident, which ſerves to confirm their prejudices, and let ſlip out of their minds all inſtances, that make againſt them [d]. There is alſo a farther impediment to true knowledge, mentioned under the ſame head by this noble writer, which is; that whereas, through the weakneſs and imperfection of our ſenſes, many things are concealed

[a] Aph. 45.
[b] Des Cartes Princ. Phil. Part. 3. §. 52.
[c] Fermat, in Oper. pag. 156, &c.
[d] Nov. Org. Aph. 46.

from

from us, which have the greateſt effect in producing natural appearances; our minds are ordinarily moſt affected by that, which makes the ſtrongeſt impreſſion on our organs of ſenſe; whereby we are apt to judge of the real importance of things in nature by a wrong meaſure [a]. So, becauſe the figuration and the motion of bodies ſtrike our ſenſes more immediately than moſt of their other properties, DES CARTES and his followers will not allow any other explication of natural appearances, than from the figure and motion of the parts of matter. By which example we ſee how juſtly his Lordſhip obſerves this cauſe of error to be the greateſt of any [b]; ſince it has given riſe to a fundamental principle in a ſyſtem of philoſophy, that not long ago obtained almoſt an univerſal reputation.

9. THESE are the chief branches of thoſe obſtructions to knowledge, which this author has reduced under his firſt head of falſe conceptions. The ſecond head contains the errors, to which particular perſons are more eſpecially obnoxious [c]. One of theſe is the conſequence of a preceding obſervation: that as we are expoſed to be captivated by any opinions, which have once taken poſſeſſion of our minds; ſo in particular, natural knowledge has been much corrupted by the ſtrong attachment of men to ſome one part of ſcience, of which they reputed themſelves the inventers, or about which they have ſpent much of their time; and hence have been apt to conceive it to be of greater uſe in the ſtudy of na-

[a] Aph. 50.
[b] Ibid.
[c] Aph. 53.

tural

tural philoſophy than it was: like ARISTOTLE, who reduced his phyſics to logical diſputations; and the chymiſts, who thought, that nature could be laid open only by the force of their fires [a]. Some again are wholly carried away by an exceſſive veneration for antiquity; others, by too great fondneſs for the moderns; few having their minds ſo well balanced, as neither to depreciate the merit of the ancients, nor yet to deſpiſe the real improvements of later times [b]. To this is added by his Lordſhip a difference in the genius of men, that ſome are moſt fitted to obſerve the ſimilitude, there is in things, while others are more qualified to diſcern the particulars, wherein they diſagree; both which diſpoſitions of mind are uſeful: but to the prejudice of philoſophy men are apt to run into exceſs in each; while one ſort of genius dwells too much upon the groſs and ſum of things, and the other upon trifling minuteneſſes and ſhadowy diſtinctions [c].

10. UNDER the third head of prejudices and falſe notions this writer conſiders ſuch, as follow from the lax and indefinite uſe of words in ordinary diſcourſe; which occaſions great ambiguities and uncertainties in philoſophical debates (as another eminent philoſopher has ſince ſhewn more at large [d];) inſomuch that this our author thinks a ſtrict defining of terms to be ſcarce an infallible remedy againſt this inconvenience [e]. And perhaps he has no ſmall reaſon on his ſide: for the common inaccurate ſenſe of words, notwithſtanding the limitations given them by definitions, will offer it ſelf ſo conſtantly to

[a] Aph. 54.
[b] Aph. 56.
[c] Aph. 55.
[d] Locke, On human underſtanding, B. iii.
[e] Nov. Org. Aph. 59.

the mind, as to require great caution and circumſpection for us not to be deceived thereby. Of this we have a very eminent inſtance in the great diſputes, that have been raiſed about the uſe of the word attraction in philoſophy; of which we ſhall be obliged hereafter to make particular mention [a]. Words thus to be guarded againſt are of two kinds. Some are names of things, that are only imaginary [b]; ſuch words are wholly to be rejected. But there are other terms, that allude to what is real, though their ſignification is confuſed [c]. And theſe latter muſt of neceſſity be continued in uſe; but their ſenſe cleared up, and freed, as much as poſſible, from obſcurity.

11. THE laſt general head of theſe errors comprehends ſuch, as follow from the various ſects of falſe philoſophies; which this author divides into three ſorts, the ſophiſtical, empirical, and ſuperſtitious [d]. By the firſt of theſe he means a philoſophy built upon ſpeculations only without experiments [e]; by the ſecond, where experiments are blindly adhered to, without proper reaſoning upon them [f]; and by the third, wrong opinions of nature fixed in mens minds either through falſe religions, or from miſunderſtanding the declarations of the true [g].

12. THESE are the four principal canals, by which this judicious author thinks, that philoſophical errors have flowed in upon us. And he rightly obſerves, that the faulty method of

[a] In the concluſion.
[b] Nov. Org. L. i. Aph. 59.
[c] Ibid. Aph. 60.
[d] Ibid. Aph. 62.
[e] Aph. 63.
[f] Aph. 64.
[g] Aph. 65.

proceeding

proceeding in philoſophy, againſt which he writes [a], is ſo far from aſſiſting us towards overcoming theſe prejudices; that he apprehends it rather ſuited to rivet them more firmly to the mind [b]. How great reaſon then has his Lordſhip to call this way of philoſophizing the parent of error, and the bane of all knowledge [c]? For, indeed, what elſe but miſtakes can ſo bold and preſumptuous a treatment of nature produce? have we the wiſdom neceſſary to frame a world, that we ſhould think ſo eaſily, and with ſo ſlight a ſearch to enter into the moſt ſecret ſprings of nature, and diſcover the original cauſes of things? what chimeras, what monſters has not this prepoſterous method brought forth? what ſchemes, or what hypotheſis's of the ſubtileſt wits has not a ſtricter enquiry into nature not only overthrown, but manifeſted to be ridiculous and abſurd? Every new improvement, which we make in this ſcience, lets us ſee more and more the weakneſs of our gueſſes. Dr. HARVEY, by that one diſcovery of the circulation of the blood, has diſſipated all the ſpeculations and reaſonings of many ages upon the animal oeconomy. ASELLIUS, by detecting the lacteal veins, ſhewed how little ground all phyſicians and philoſophers had in conjecturing, that the nutritive part of the aliment was abſorbed by the mouths of the veins ſpread upon the bowels: and then PECQUET, by finding out the thoracic duct, as evidently proved the vanity of the opinion, which was perſiſted in after the lacteal veſſels were known, that the alimental juice was conveyed immediately to the liver, and there converted into blood.

[a] See above, § 4, 5.
[b] Nov. Org. L. i. Aph. 69.
[c] Ibid.

13. As theſe things ſet forth the great abſurdity of proceeding in philoſophy on conjectures, by informing us how far the operations of nature are above our low conceptions; ſo on the other hand, ſuch inſtances of ſucceſs from a more judicious method ſhew us, that our bountiful maker has not left us wholly without means of delighting our ſelves in the contemplation of his wiſdom. That by a juſt way of inquiry into nature, we could not fail of arriving at diſcoveries very remote from our apprehenſions; the Lord BACON himſelf argues from the experience of mankind. If, ſays he, the force of guns ſhould be deſcribed to any one ignorant of them, by their effects only; he might reaſonably ſuppoſe, that thoſe engines of deſtruction were only a more artificial compoſition, than he knew, of wheels and other mechanical powers: but it could never enter his thoughts, that their immenſe force ſhould be owing to a peculiar ſubſtance, which would enkindle into ſo violent an exploſion, as we experience in gunpowder: ſince he would no where ſee the leaſt example of any ſuch operation; except perhaps in earthquakes and thunder, which he would doubtleſs look upon as exalted powers of nature, greatly ſurpaſſing any art of man to imitate. In the ſame manner, if a ſtranger to the original of ſilk were ſhewn a garment made of it, he would be very far from imagining ſo ſtrong a ſubſtance to be ſpun out of the bowels of a ſmall worm; but muſt certainly believe it either a vegetable ſubſtance, like flax or cotton; or the natural covering of ſome animal, as wool is of ſheep. Or had we been told, before the invention of the magnetic needle among us, that another people was in poſſeſſion of a certain contrivance

contrivance, by which they were inabled to diſcover the poſition of the heavens, with vaſtly more eaſe, than we could do; what could have been imagined more, than that they were provided with ſome fitter aſtronomical inſtrument for this purpoſe than we? That any ſtone ſhould have ſo amazing a property, as we find in the magnet, muſt have been the remoteſt from our thoughts [a].

14. BUT what ſurprizing advancements in the knowledge of nature may be made by purſuing the true courſe in philoſophical inquiries; when thoſe ſearches are conducted by a genius equal to ſo divine a work, will be beſt underſtood by conſidering Sir ISAAC NEWTON'S diſcoveries. That my reader may apprehend as juſt a notion of theſe, as can be conveyed to him, by the brief account, which I intend to lay before him; I have ſet apart this introduction for explaining, in the fulleſt manner I am able, the principles, whereon Sir ISAAC NEWTON proceeds. For without a clear conception of theſe, it is impoſſible to form any true idea of the ſingular excellence of the inventions of this great philoſopher.

15. THE principles then of this philoſophy are; upon no conſideration to indulge conjectures concerning the powers and laws of nature, but to make it our endeavour with all diligence to ſearch out the real and true laws, by which the conſtitution of things is regulated. The philoſopher's firſt care muſt be to diſtinguiſh, what he ſees to be within his power, from what

[a] Ibid. Aph. 109.

is beyond his reach; to aſſume no greater degree of knowledge, than what he finds himſelf poſſeſſed of; but to advance by ſlow and cautious ſteps; to ſearch gradually into natural cauſes; to ſecure to himſelf the knowledge of the moſt immediate cauſe of each appearance, before he extends his views farther to cauſes more remote. This is the method, in which philoſophy ought to be cultivated; which does not pretend to ſo great things, as the more airy ſpeculations; but will perform abundantly more: we ſhall not perhaps ſeem to the unskilful to know ſo much, but our real knowledge will be greater. And certainly it is no objection againſt this method, that ſome others promiſe, what is nearer to the extent of our wiſhes: ſince this, if it will not teach us all we could deſire to be informed of, will however give us ſome true light into nature; which no other can do. Nor has the philoſopher any reaſon to think his labour loſt, when he finds himſelf ſtopt at the cauſe firſt diſcovered by him, or at any other more remote cauſe, ſhort of the original: for if he has but ſufficiently proved any one cauſe, he has entered ſo far into the real conſtitution of things, has laid a ſafe foundation for others to work upon, and has facilitated their endeavours in the ſearch after yet more diſtant cauſes; and beſides, in the mean time he may apply the knowledge of theſe intermediate cauſes to many uſeful purpoſes. Indeed the being able to make practical deductions from natural cauſes, conſtitutes the great diſtinction between the true philoſophy and the falſe. Cauſes aſſumed upon conjecture, muſt be ſo looſe and undefined, that nothing particular can be collected from them. But thoſe cauſes, which are brought to light by a ſtrict examination

of

of things, will be more diſtinct. Hence it appears to have been no unuſeful diſcovery, that the aſcent of water in pumps is owing to the preſſure of the air by its weight or ſpring; though the cauſes, which make the air gravitate, and render it elaſtic, be unknown: for notwithſtanding we are ignorant of the original, whence theſe powers of the air are derived; yet we may receive much advantage from the bare knowledge of theſe powers. If we are but certain of the degree of force, wherewith they act, we ſhall know the extent of what is to be expected from them; we ſhall know the greateſt height, to which it is poſſible by pumps to raiſe water; and ſhall thereby be prevented from making any uſeleſs efforts towards improving theſe inſtruments beyond the limits preſcribed to them by nature; whereas without ſo much knowledge as this, we might probably have waſted in attempts of this kind much time and labour. How long did philoſophers buſy themſelves to no purpoſe in endeavouring to perfect teleſcopes, by forming the glaſſes into ſome new figure; till Sir ISAAC NEWTON demonſtrated, that the effects of teleſcopes were limited from another cauſe, than was ſuppoſed; which no alteration in the figure of the glaſſes could remedy? What method Sir ISAAC NEWTON himſelf has found for the improvement of teleſcopes ſhall be explained hereafter [a]. But at preſent I ſhall proceed to illuſtrate, by ſome farther inſtances, this diſtinguiſhing character of the true philoſophy, which we have now under conſideration. It was no trifling diſcovery, that the contraction of the muſcles of animals puts their limbs in motion, though the original cauſe of that contraction

[a] Book III. Chap. iv.

remains

remains a ſecret, and perhaps may always do ſo; for the knowledge of thus much only has given riſe to many ſpeculations upon the force and artificial diſpoſition of the muſcles, and has opened no narrow proſpect into the animal fabrick. The finding out, that the nerves are great agents in this action, leads us yet nearer to the original cauſe, and yields us a wider view of the ſubject. And each of theſe ſteps affords us aſſiſtance towards reſtoring this animal motion, when impaired in our ſelves, by pointing out the ſeats of the injuries, to which it is obnoxious. To neglect all this, becauſe we can hitherto advance no farther, is plainly ridiculous. It is confeſſed by all, that GALILEO greatly improved philoſophy, by ſhewing, as we ſhall relate hereafter, that the power in bodies, which we call gravity, occaſions them to move downwards with a velocity equably accelerated[a]; and that when any body is thrown forwards, the ſame power obliges it to deſcribe in its motion that line, which is called by geometers a parabola[b]: yet we are ignorant of the cauſe, which makes bodies gravitate. But although we are unacquainted with the ſpring, whence this power in nature is derived, nevertheleſs we can eſtimate its effects. When a body falls perpendicularly, it is known, how long time it takes in deſcending from any height whatever: and if it be thrown forwards, we know the real path, which it deſcribes; we can determine in what direction, and with what degree of ſwiftneſs it muſt be projected, in order to its ſtriking againſt any object deſired; and we can alſo aſcertain the very force, wherewith it will ſtrike.

[a] Book I. Chap. 2. § 14. [b] Ibid. § 85, &c.

Sir

Sir ISAAC NEWTON has farther taught, that this power of gravitation extends up to the moon, and cauſes that planet to gravitate as much towards the earth, as any of the bodies, which are familiar to us, would, if placed at the ſame diſtance [a]: he has proved likewiſe, that all the planets gravitate towards the ſun, and towards one another; and that their reſpective motions follow from this gravitation. All this he has demonſtrated upon indiſputable geometrical principles, which cannot be rendered precarious for want of knowing what it is, which cauſes theſe bodies thus mutually to gravitate: any more than we can doubt of the propenſity in all the bodies about us, to deſcend towards the earth; or can call in queſtion the forementioned propoſitions of GALILEO, which are built upon that principle. And as GALILEO has ſhewn more fully, than was known before, what effects were produced in the motion of bodies by their gravitation towards the earth; ſo Sir ISAAC NEWTON, by this his invention, has much advanced our knowledge in the celeſtial motions. By diſcovering that the moon gravitates towards the ſun, as well as towards the earth; he has laid open thoſe intricacies in the moon's motion, which no aſtronomer, from obſervations only, could ever find out [b]: and one kind of heavenly bodies, the comets, have their motion now clearly aſcertained; whereof we had before no true knowledge at all [c].

16. DOUBTLESS it might be expected, that ſuch ſurprizing ſucceſs ſhould have ſilenced, at once, every cavil. But we

[a] See Book II. Ch. 3. § 3, 4. of this treatiſe.
[b] See Book II. Ch. 3. of this treatiſe.
[c] See Chap. 4.

have ſeen the contrary. For becauſe this philoſophy profeſſes modeſtly to keep within the extent of our faculties, and is ready to confeſs its imperfections, rather than to make any fruitleſs attempts to conceal them, by ſeeking to cover the defects in our knowledge with the vain oſtentation of raſh and groundleſs conjectures; hence has been taken an occaſion to inſinuate that we are led to miraculous cauſes, and the occult qualities of the ſchools.

17. But the firſt of theſe accuſations is very extraordinary. If by calling theſe cauſes miraculous nothing more is meant than only, that they often appear to us wonderful and ſurprizing, it is not eaſy to ſee what difficulty can be raiſed from thence; for the works of nature diſcover every where ſuch proofs of the unbounded power, and the conſummate wiſdom of their author, that the more they are known, the more they will excite our admiration: and it is too manifeſt to be inſiſted on, that the common ſenſe of the word miraculous can have no place here, when it implies what is above the ordinary courſe of things. The other imputation, that theſe cauſes are occult upon the account of our not perceiving what produces them, contains in it great ambiguity. That ſomething relating to them lies hid, the followers of this philoſophy are ready to acknowledge, nay deſire it ſhould be carefully remarked, as pointing out proper ſubjects for future inquiry. But this is very different from the proceeding of the ſchoolmen in the cauſes called by them occult. For as their occult qualities were underſtood to operate in a manner occult, and not apprehended by us; ſo they were ob-

truded upon us for ſuch original and eſſential properties in bodies, as made it vain to ſeek any farther cauſe; and a greater power was attributed to them, than any natural appearances authorized. For inſtance, the riſe of water in pumps was aſcribed to a certain abhorrence of a vacuum, which they thought fit to aſſign to nature. And this was ſo far a true obſervation, that the water does move, contrary to its uſual courſe, into the ſpace, which otherwiſe would be left void of any ſenſible matter; and, that the procuring ſuch a vacuity was the apparent cauſe of the water's aſcent. But while we were not in the leaſt informed how this power, called an abhorrence of a vacuum, produced the viſible effects; inſtead of making any advancement in the knowledge of nature, we only gave an artificial name to one of her operations: and when the ſpeculation was puſhed ſo beyond what any appearances required, as to have it concluded, that this abhorrence of a vacuum was a power inherent in all matter, and ſo unlimited as to render it impoſſible for a vacuum to exiſt at all; it then became a much greater abſurdity, in being made the foundation of a moſt ridiculous manner of reaſoning; as at length evidently appeared, when it came to be diſcovered, that this riſe of the water followed only from the preſſure of the air, and extended it ſelf no farther, than the power of that cauſe. The ſcholaſtic ſtile in diſcourſing of theſe occult qualities, as if they were eſſential differences in the very ſubſtances, of which bodies conſiſted, was certainly very abſurd; by reaſon it tended to diſcourage all farther inquiry. But no ſuch ill conſequences can follow from the conſidering of any natural cauſes, which confeſſedly are not traced up to

their firſt original. How ſhall we ever come to the knowledge of the ſeveral original cauſes of things, otherwiſe than by ſtoring up all intermediate cauſes which we can diſcover? Are all the original and eſſential properties of matter ſo very obvious, that none of them can eſcape our firſt view? This is not probable. It is much more likely, that, if ſome of the eſſential properties are diſcovered by our firſt obſervations, a ſtricter examination ſhould bring more to light.

18. BUT in order to clear up this point concerning the eſſential properties of matter, let us conſider the ſubject a little diſtinctly. We are to conceive, that the matter, out of which the univerſe of things is formed, is furniſhed with certain qualities and powers, whereby it is rendered fit to anſwer the purpoſes, for which it was created. But every property, of which any particle of this matter is in it ſelf poſſeſſed, and which is not barely the conſequence of the union of this particle with other portions of matter, we may call an eſſential property: whereas all other qualities or attributes belonging to bodies, which depend on their particular frame and compoſition, are not eſſential to the matter, whereof ſuch bodies are made; becauſe the matter of theſe bodies will be deprived of thoſe qualities, only by the diſſolution of the body, without working any change in the original conſtitution of one ſingle particle of this maſs of matter. Extenſion we apprehend to be one of theſe eſſential properties, and impenetrability another. Theſe two belong univerſally to all matter; and are the principal ingredients in the idea, which this word matter uſually excites in the mind. Yet as the idea, marked

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by this name, is not purely the creature of our own underſtandings, but is taken for the repreſentation of a certain ſubſtance without us; if we ſhould diſcover, that every part of the ſubſtance, in which we find theſe two properties, ſhould likewiſe be endowed univerſally with any other eſſential qualities; all theſe, from the time they come to our notice, muſt be united under our general idea of matter. How many ſuch properties there are actually in all matter we know not; thoſe, of which we are at preſent apprized, have been found out only by our obſervations on things; how many more a farther ſearch may bring to light, no one can ſay; nor are we certain, that we are provided with ſufficient methods of perception to diſcern them all. Therefore, ſince we have no other way of making diſcoveries in nature, but by gradual inquiries into the properties of bodies; our firſt ſtep muſt be to admit without diſtinction all the properties, which we obſerve; and afterwards we muſt endeavour, as far as we are able, to diſtinguiſh between the qualities, wherewith the very ſubſtances themſelves are indued, and thoſe appearances, which reſult from the ſtructure only of compound bodies. Some of the properties, which we obſerve in things, are the attributes of particular bodies only; others univerſally belong to all, that fall under our notice. Whether ſome of the qualities and powers of particular bodies, be derived from different kinds of matter entring their compoſition, cannot, in the preſent imperfect ſtate of our knowledge, abſolutely be decided; though we have not yet any reaſon to conclude, but that all the bodies, with which we converſe, are framed out of the very ſame kind of matter, and that their diſtinct

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qualities are occaſioned only by their ſtructure; through the variety whereof the general powers of matter are cauſed to produce different effects. On the other hand, we ſhould not haſtily conclude, that whatever is found to appertain to all matter, which falls under our examination, muſt for that reaſon only be an eſſential property thereof, and not be derived from ſome unſeen diſpoſition in the frame of nature. Sir ISAAC NEWTON has found reaſon to conclude, that gravity is a property univerſally belonging to all the perceptible bodies in the univerſe, and to every particle of matter, whereof they are compoſed. But yet he no where aſſerts this property to be eſſential to matter. And he was ſo far from having any deſign of eſtabliſhing it as ſuch, that, on the contrary, he has given ſome hints worthy of himſelf at a cauſe for it [a]; and expreſly ſays, that he propoſed thoſe hints to ſhew, that he had no ſuch intention [b].

19. IT appears from hence, that it is not eaſy to determine, what properties of bodies are eſſentially inherent in the matter, out of which they are made, and what depend upon their frame and compoſition. But certainly whatever properties are found to belong either to any particular ſyſtems of matter, or univerſally to all, muſt be conſidered in philoſophy; becauſe philoſophy will be otherwiſe imperfect. Whether thoſe properties can be deduced from ſome other appertaining to matter, either among thoſe, which are already known, or among ſuch as can be diſcovered by us, is afterwards to be ſought for the farther improvement of our knowledge. But this

[a] At the end of his Optics. in Qu. 21.

[b] See the ſame treatiſe, in Advertiſement 2.

inquiry

inquiry cannot properly have place in the deliberation about admitting any property of matter or bodies into philoſophy; for that purpoſe it is only to be conſidered, whether the exiſtence of ſuch a property has been juſtly proved or not. Therefore to decide what cauſes of things are rightly received into natural philoſophy, requires only a diſtinct and clear conception of what kind of reaſoning is to be allowed of as convincing, when we argue upon the works of nature.

20. THE proofs in natural philoſophy cannot be ſo abſolutely concluſive, as in the mathematics. For the ſubjects of that ſcience are purely the ideas of our own minds. They may be repreſented to our ſenſes by material objects, but they are themſelves the arbitrary productions of our own thoughts; ſo that as the mind can have a full and adequate knowledge of its own ideas, the reaſoning in geometry can be rendered perfect. But in natural knowledge the ſubject of our contemplation is without us, and not ſo compleatly to be known: therefore our method of arguing muſt fall a little ſhort of abſolute perfection. It is only here required to ſteer a juſt courſe between the conjectural method of proceeding, againſt which I have ſo largely ſpoke; and demanding ſo rigorous a proof, as will reduce all philoſophy to mere ſcepticiſm, and exclude all proſpect of making any progreſs in the knowledge of nature.

21. THE conceſſions, which are to be allowed in this ſcience, are by Sir ISAAC NEWTON included under a very few ſimple precepts.

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22. THE firſt is, that more cauſes are not to be received into philoſophy, than are ſufficient to explain the appearances of nature. That this rule is approved of unanimouſly, is evident from thoſe expreſſions ſo frequent among all philoſophers, that nature does nothing in vain; and that a variety of means, where fewer would ſuffice, is needleſs. And certainly there is the higheſt reaſon for complying with this rule. For ſhould we indulge the liberty of multiplying, without neceſſity, the cauſes of things, it would reduce all philoſophy to mere uncertainty; ſince the only proof, which we can have, of the exiſtence of a cauſe, is the neceſſity of it for producing known effects. Therefore where one cauſe is ſufficient, if there really ſhould in nature be two, which is in the laſt degree improbable, we can have no poſſible means of knowing it, and conſequently ought not to take the liberty of imagining, that there are more than one.

23. THE ſecond precept is the direct conſequence of the firſt, that to like effects are to be aſcribed the ſame cauſes. For inſtance, that reſpiration in men and in brutes is brought about by the ſame means; that bodies deſcend to the earth here in EUROPE, and in AMERICA from the ſame principle; that the light of a culinary fire, and of the ſun have the ſame manner of production; that the reflection of light is effected in the earth, and in the planets by the ſame power; and the like.

24. THE third of theſe precepts has equally evident reaſon for it. It is only, that thoſe qualities, which in the ſame body can neither be leſſened nor increaſed, and which belong to

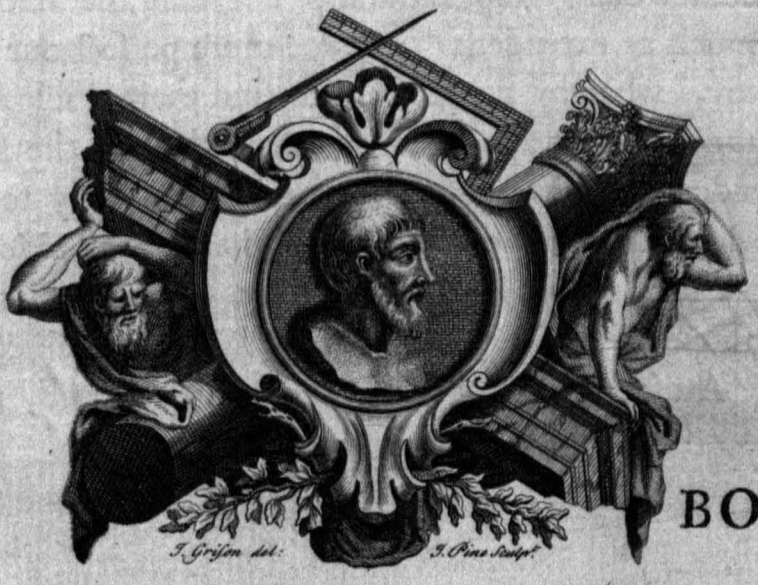
to all bodies that are in our power to make trial upon, ought to be accounted the univerſal properties of all bodies whatever.*

25. In this precept is founded that method of arguing by induction, without which no progreſs could be made in natural philoſophy. For as the qualities of bodies become known to us by experiments only; we have no other way of finding the properties of ſuch bodies, as are out of our reach to experiment upon, but by drawing concluſions from thoſe which fall under our examination. The only caution here required is, that the obſervations and experiments, we argue upon, be numerous enough, and that due regard be paid to all objections, that occur, as the Lord Bacon very judiciouſly directs [a]. And this admonition is ſufficiently complied with, when by virtue of this rule we aſcribe impenetrability and extenſion to all bodies, though we have no ſenſible experiment, that affords a direct proof of any of the celeſtial bodies being impenetrable; nor that the fixed ſtars are ſo much as extended. For the more perfect our inſtruments are, whereby we attempt to find their viſible magnitude, the leſs they appear; inſomuch that all the ſenſible magnitude, which we obſerve in them, ſeems only to be an optical deception by the ſcattering of their light. However, I ſuppoſe no one will imagine they are without any magnitude, though their immenſe diſtance makes it undiſcernable by us. After the ſame manner, if it can be proved, that all

[a] Nov. Org. Lib. i. Ax. 105.

bodies here gravitate towards the earth, in proportion to the quantity of ſolid matter in each; and that the moon gravitates to the earth likewiſe, in proportion to the quantity of matter in it; and that the ſea gravitates towards the moon, and all the planets towards each other; and that the very comets have the ſame gravitating faculty; we ſhall have as great reaſon to conclude by this rule, that all bodies gravitate towards each other. For indeed this rule will more ſtrongly hold in this caſe, than in that of the impenetrability of bodies; becauſe there will more inſtances be had of bodies gravitating, than of their being impenetrable.

25. THIS is that method of induction, whereon all philoſophy is founded; which our author farther inforces by this additional precept, that whatever is collected from this induction, ought to be received, notwithſtanding any conjectural hypotheſis to the contrary, till ſuch times as it ſhall be contradicted or limited by farther obſervations on nature.



BOOK

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BOOK I.

CONCERNING THE MOTION of BODIES IN GENERAL.

CHAP. I.

Of the LAWS of MOTION.

HAVING thus explained Sir ISAAC NEWTON'S method of reaſoning in philoſophy, I ſhall now proceed to my intended account of his diſcoveries. Theſe are contained in two treatiſes. In one of them, the MATHEMATICAL PRINCIPLES OF NATURAL PHILOSOPHY, his chief deſign is to ſhew by what laws the heavenly

motions are regulated; in the other, his OPTICS, he diſcourſes of the nature of light and colours, and of the action between light and bodies. This ſecond treatiſe is wholly confined to the ſubject of light: except ſome conjectures propoſed at the end concerning other parts of nature, which lie hitherto more concealed. In the other treatiſe our author was obliged to ſmooth the way to his principal intention, by explaining many things of a more general nature: for even ſome of the moſt ſimple properties of matter were ſcarce well eſtabliſhed at that time. We may therefore reduce Sir ISAAC NEWTON'S doctrine under three general heads; and I ſhall accordingly divide my account into three books. In the firſt I ſhall ſpeak of what he has delivered concerning the motion of bodies, without regard to any particular ſyſtem of matter; in the ſecond I ſhall treat of the heavenly motions; and the third ſhall be employed upon light.

2. IN the firſt part of my deſign, we muſt begin with an account of the general laws of motion.

3. THESE laws are ſome univerſal affections and properties of matter drawn from experience, which are made uſe of as axioms and evident principles in all our arguings upon the motion of bodies. For as it is the cuſtom of geometers to aſſume in their demonſtrations ſome propoſitions, without exhibiting the proof of them; ſo in philoſophy, all our reaſoning muſt be built upon ſome properties of matter, firſt admitted as principles whereon to argue. In geometry theſe axioms are thus aſſumed, on account of their being ſo evident

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as to make any proof in form needleſs. But in philoſophy no properties of bodies can be in this manner received for ſelf-evident; ſince it has been obſerved above, that we can conclude nothing concerning matter by any reaſonings upon its nature and eſſence, but that we owe all the knowledge, we have thereof, to experience. Yet when our obſervations on matter have inform'd us of ſome of its properties, we may ſecurely reaſon upon them in our farther inquiries into nature. And theſe laws of motion, of which I am here to ſpeak, are found ſo univerſally to belong to bodies, that there is no motion known, which is not regulated by them. Theſe are by Sir ISAAC NEWTON reduced to three [a].

4. THE firſt law is, that all bodies have ſuch an indifference to reſt, or motion, that if once at reſt they remain ſo, till diſturbed by ſome power acting upon them: but if once put in motion, they perſiſt in it; continuing to move right forwards perpetually, after the power, which gave the motion, is removed; and alſo preſerving the ſame degree of velocity or quickneſs, as was firſt communicated, not ſtopping or remitting their courſe, till interrupted or otherwiſe diſturbed by ſome new power impreſſed.

5. THE ſecond law of motion is, that the alteration of the ſtate of any body, whether from reſt to motion, or from motion to reſt, or from one degree of motion to another, is always proportional to the force impreſſed. A body at reſt, when

[a] Princip. philoſ. pag. 13, 14.

acted

acted upon by any power, yields to that power, moving in the ſame line, in which the power applied is directed; and moves with a leſs or greater degree of velocity, according to the degree of the power; ſo that twice the power ſhall communicate a double velocity, and three times the power a threefold velocity. If the body be moving, and the power impreſſed act upon the body in the direction of its motion, the body ſhall receive an addition to its motion, as great as the motion, into which that power would have put it from a ſtate of reſt; but if the power impreſſed upon a moving body act directly oppoſite to its former motion, that power ſhall then take away from the body's motion, as much as in the other caſe it would have added to it. Laſtly, if the power be impreſſed obliquely, there will ariſe an oblique motion differing more or leſs from the former direction, according as the new impreſſion is greater or leſs. For example, if the body A (in fig. 1.) be moving in the direction A B, and when it is at the point A, a power be impreſſed upon it in the direction A C, the body ſhall from henceforth neither move in its firſt direction A B, nor in the direction of the adventitious power, but ſhall take a courſe as A D between them: and if the power laſt impreſſed be juſt equal to that, which firſt gave to the body its motion; the line A D ſhall paſs in the middle between A B and A C, dividing the angle under B A C into two equal parts; but if the power laſt impreſſed be greater than the firſt, the line A D ſhall incline moſt to A C; whereas if the laſt impreſſion be leſs than the firſt, the line A D ſhall incline moſt to A B. To be more particular, the ſituation of

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the line AD is always to be determined after this manner. Let AE be the ſpace, which the body would have moved through in the line AB during any certain portion of time; provided that body, when at A, had received no ſecond impulſe. Suppoſe likewiſe, that AF is the part of the line AC, through which the body would have moved during an equal portion of time, if it had been at reſt in A, when it received the impulſe in the direction AC: then if from E be drawn a line parallel to, or equidiſtant from AC, and from F another line parallel to AB, thoſe two lines will meet in the line AD.

6. THE third and laſt of theſe laws of motion is, that when any body acts upon another, the action of that body upon the other is equalled by the contrary reaction of that other body upon the firſt.

7. THESE laws of motion are abundantly confirmed by this, that all the deductions made from them, in relation to the motion of bodies, how complicated ſoever, are found to agree perfectly with obſervation. This ſhall be ſhewn more at large in the next chapter. But before we proceed to ſo diffuſive a proof; I chuſe here to point out thoſe appearances of bodies, whereby the laws of motion are firſt ſuggeſted to us.

8. DAILY obſervation makes it appear to us, that any body, which we once ſee at reſt, never puts it ſelf into freſh motion;

motion; but continues always in the ſame place, till removed by ſome power applied to it.

9. AGAIN, whenever a body is once in motion, it continues in that motion ſome time after the moving power has quitted it, and it is left to it ſelf. Now if the body continue to move but a ſingle moment, after the moving power has left it, there can no reaſon be aſſigned, why it ſhould ever ſtop without ſome external force. For it is plain, that this continuance of the motion is cauſed only by the body's having already moved, the ſole operation of the power upon the body being the putting it in motion; therefore that motion continued will equally be the cauſe of its farther motion, and ſo on without end. The only doubt that can remain, is, whether this motion communicated continues intire, after the power, that cauſed it, ceaſes to act; or whether it does not gradually languiſh and decreaſe. And this ſuſpicion cannot be removed by a tranſient and ſlight obſervation on bodies, but will be fully cleared up by thoſe more accurate proofs of the laws of motion, which are to be conſidered in the next chapter.

10. LASTLY, bodies in motion appear to affect a ſtraight courſe without any deviation, unleſs when diſturbed by ſome adventitious power acting upon them. If a body be thrown perpendicularly upwards or downwards, it appears to continue in the ſame ſtraight line during the whole time of its motion. If a body be thrown in any other direction, it is found to deviate from the line, in which it began to move, more and more

more continually towards the earth, whither it is directed by its weight: but ſince, when the weight of a body does not alter the direction of its motion, it always moves in a ſtraight line, without doubt in this other caſe the body's declining from its firſt courſe is no more, than what is cauſed by its weight alone. As this appears at firſt ſight to be unqueſtionable, ſo we ſhall have a very diſtinct proof thereof in the next chapter, where the oblique motion of bodies will be particularly conſidered.

II. THUS we ſee how the firſt of the laws of motion agrees with what appears to us in moving bodies. But here occurs this farther conſideration, that the real and abſolute motion of any body is not viſible to us: for we are our ſelves alſo in conſtant motion along with the earth whereon we dwell; inſomuch that we perceive bodies to move ſo far only, as their motion is different from our own. When a body appears to us to lie at reſt, in reality it only continues the motion, it has received, without putting forth any power to change that motion. If we throw a body in the courſe or direction, wherein we are carried our ſelves; ſo much motion as we ſeem to have given to the body, ſo much we have truly added to the motion, it had, while it appeared to us to be at reſt. But if we impel a body the contrary way, although the body appears to us to have received by ſuch an impulſe as much motion, as when impelled the other way; yet in this caſe we have taken from the body ſo much real motion, as we ſeem to have given it. Thus the motion, which we ſee in bodies,

is not their real motion, but only relative with reſpect to us; and the forementioned obſervations only ſhew us, that this firſt law of motion has place in this relative or apparent motion. However, though we cannot make any obſervation immediately on the abſolute motion of bodies, yet by reaſoning upon what we obſerve in viſible motion, we can diſcover the properties and effects of real motion.

12. WITH regard to this firſt law of motion, which is now under conſideration, we may from the foregoing obſervations moſt truly collect, that bodies are diſpoſed to continue in the abſolute motion, which they have once received, without increaſing or diminiſhing their velocity. When a body appears to us to lie at reſt, it really preſerves without change the motion, which it has in common with our ſelves: and when we put it into viſible motion, and we ſee it continue that motion; this proves, that the body retains that degree of its abſolute motion, into which it is put by our acting upon it: if we give it ſuch an apparent motion, which adds to its real motion, it preſerves that addition; and if our acting on the body takes off from its real motion, it continues afterwards to move with no more real motion, than we have left it.

13. AGAIN, we do not obſerve in bodies any diſpoſition or power within themſelves to change the direction of their motion; and if they had any ſuch power, it would eaſily be diſcovered. For ſuppoſe a body by the ſtructure or diſpoſition of its parts, or by any other circumſtance in its make, was indued

dued with a power of moving it ſelf; this ſelf-moving principle, which ſhould be thus inherent in the body, and not depend on any thing external, muſt change the direction wherein it would act, as often as the poſition of the body was changed: ſo that for inſtance, if a body was lying before me in ſuch a poſition, that the direction, wherein this principle diſpoſes the body to move, was pointed directly from me; if I then gradually turned the body about, the direction of this ſelf-moving principle would no longer be pointed directly from me, but would turn about along with the body. Now if any body, which appears to us at reſt, were furniſhed with any ſuch ſelf-moving principle; from the body's appearing without motion we muſt conclude, that this ſelf-moving principle lies directed the ſame way as the earth is carrying the body; and ſuch a body might immediately be put into viſible motion only by turning it about in any degree, that this ſelf-moving principle might receive a different direction.

14. FROM theſe conſiderations it very plainly follows, that if a body were once abſolutely at reſt; not being furniſhed with any principle, whereby it could put it ſelf into motion, it muſt for ever continue in the ſame place, till acted upon by ſomething external: and alſo that when a body is put into motion, it has no power within it ſelf to make any change in the direction of that motion; and conſequently that the body muſt move on ſtraight forward without declining any way whatever. But it has before been ſhewn, that bodies do not appear to have in themſelves any power to

change the velocity of their motion: therefore this firſt law of motion has been illuſtrated and confirmed, as much as can be from the tranſient obſervations, which have here been diſcourſed upon; and in the next chapter all this will be farther eſtabliſhed by more correct obſervations.

15. BUT I ſhall now paſs to the ſecond law of motion; wherein, when it is aſſerted, that the velocity, with which any body is moved by the action of a power upon it, is proportional to that power; the degree of power is ſuppoſed to be meaſured by the greatneſs of the body, which it can move with a given celerity. So that the ſenſe of this law is, that if any body were put into motion with that degree of ſwiftneſs, as to paſs in one hour the length of a thouſand yards; the power, which would give the ſame degree of velocity to a body twice as great, would give this leſſer body twice the velocity, cauſing it to deſcribe in the ſame ſpace of an hour two thouſand yards. But by a body twice as great as another, I do not here mean ſimply of twice the bulk, but one that contains a double quantity of ſolid matter.

16. WHY the power, which can move a body twice as great as another with the ſame degree of velocity, ſhould be called twice as great as the power, which can give the leſſer body the ſame velocity, is evident. For if we ſhould ſuppoſe the greater body to be divided into two equal parts, each equal to the leſſer body, each of theſe halves will require the ſame degree of power to move them with the velocity of the leſſer body, as the leſſer body it ſelf requires; and therefore both

thoſe halves, or the whole greater body, will require the moving power to be doubled.

17. THAT the moving power being in this ſenſe doubled, ſhould juſt double likewiſe the velocity of the ſame body, ſeems near as evident, if we conſider, that the effect of the power applied muſt needs be the ſame, whether that power be applied to the body at once, or in parts. Suppoſe then the double power not applied to the body at once, but half of it firſt, and afterwards the other half; it is not conceivable for what reaſon the half laſt applied ſhould come to have a different effect upon the body, from that which is applied firſt; as it muſt have, if the velocity of the body was not juſt doubled by the application of it. So far as experience can determine, we ſee nothing to favour ſuch a ſuppoſition. We cannot indeed (by reaſon of the conſtant motion of the earth) make trial upon any body perfectly at reſt, whereby to ſee whether a power applied in that caſe would have a different effect, from what it has, when the body is already moving; but we find no alteration in the effect of the ſame power on account of any difference there may be in the motion of the body, when the power is applied. The earth does not always carry bodies with the ſame degree of velocity; yet we find the viſible effects of any power applied to the ſame body to be at all times the very ſame: and a bale of goods, or other moveable body lying in a ſhip is as eaſily removed from place to place, while the ſhip is under ſail, if its motion be ſteady, as when it is fixed at anchor.

18. Now

18. NOW this experience is alone ſufficient to ſhew to us the whole of this law of motion.

19. SINCE we find, that the ſame power will always produce the ſame change in the motion of any body, whether that body were before moving with a ſwifter or ſlower motion; the change wrought in the motion of a body depends only on the power applied to it, without any regard to the body's former motion: and therefore the degree of motion, which the body already poſſeſſes, having no influence on the power applied to diſturb its operation, the effects of the ſame power will not only be the ſame in all degrees of motion of the body; but we have likewiſe no reaſon to doubt, but that a body perfectly at reſt would receive from any power as much motion, as would be equivalent to the effect of the ſame power applied to that body already in motion.

20. AGAIN, ſuppoſe a body being at reſt, any number of equal powers ſhould be ſucceſſively applied to it; puſhing it forward from time to time in the ſame courſe or direction. Upon the application of the firſt power the body would begin to move; when the ſecond power was applied, it appears from what has been ſaid, that the motion of the body would become double; the third power would treble the motion of the body; and ſo on, till after the operation of the laſt power the motion of the body would be as many times the motion, which the firſt power gave it, as there are powers in number. And the effect of this number of powers will be always the ſame,

ſame, without any regard to the ſpace of time taken up in applying them: ſo that greater or leſſer intervals between the application of each of theſe powers will produce no difference at all in their effects. Since therefore the diſtance of time between the action of each power is of no conſequence; without doubt the effect will ſtill be the ſame, though the powers ſhould all be applied at the very ſame inſtant; or although a ſingle power ſhould be applied equal in ſtrength to the collective force of all theſe powers. Hence it plainly follows, that the degree of motion, into which any body will be put out of a ſtate of reſt by any power, will be proportional to that power. A double power will give twice the velocity, a treble power three times the velocity, and ſo on. The foregoing reaſoning will equally take place, though the body were not ſuppoſed to be at reſt, when the powers began to be applied to it; provided the direction, in which the powers were applied, either conſpired with the action of the body, or was directly oppoſite to it. Therefore if any power be applied to a moving body, and act upon the body either in the direction wherewith the body moves, ſo as to accelerate the body; or if it act directly oppoſite to the motion of the body, ſo as to retard it: in both theſe caſes the change of motion will be proportional to the power applied; nay, the augmentation of the motion in one caſe, and the diminution thereof in the other, will be equal to that degree of motion, into which the ſame power would put the body, had it been at reſt, when the power was applied.

21. FARTHER, a power may be ſo applied to a moving body, as to act obliquely to the motion of the body. And the effects of ſuch an oblique motion may be deduced from this obſervation; that as all bodies are continually moving along with the earth, we ſee that the viſible effects of the ſame power are always the ſame, in whatever direction the power acts: and therefore the viſible effects of any power upon a body, which ſeems only to be at reſt, is always to appearance the ſame as the real effect would be upon a body truly at reſt. Now ſuppoſe a body were moving along the line AB (in fig. 2.) and the eye accompanied it with an equal motion in the line CD equidiſtant from AB; ſo that when the body is at A, the eye ſhall be at C, and when the body is advanced to E in the line AB, the eye ſhall be advanced to F in the line CD, the diſtances AE and CF being equal. It is evident, that here the body will appear to the eye to be at reſt; and the line FEG drawn from the eye through the body ſhall ſeem to the eye to be immoveable; though as the body and eye move forward together, this line ſhall really alſo move; ſo that when the body ſhall be advanced to H and the eye to K, the line FEG ſhall be transferred into the ſituation KHL, this line KHL being equidiſtant from FEG. Now if the body when at E were to receive an impulſe in the direction of the line FEG; while the eye is moving on from F to K, and carrying along with it the line FEG, the body will appear to the eye to move along this line FEG: for this is what has juſt now been ſaid; that while bodies are moving along with the earth, and the ſpectator's eye partakes of the ſame motion, the effect of any power upon the body will appear to be what it

it would really have been, had the body been truly at reſt, when the power was applied. From hence it follows, that when the eye is advanced to K, the body will appear ſomewhere in the line KHL. Suppoſe it appear in M; then it is manifeſt, from what has been premiſed at the beginning of this paragraph, that the diſtance HM is equal to what the body would have run upon the line EG, during the time, wherein the eye has paſſed from F to K, provided that the body had been at reſt, when acted upon in E. If it be farther asked, after what manner the body has moved from E to M? I anſwer, through a ſtraight line; for it has been ſhewn above in the explication of the firſt law of motion, that a moving body, from the time it is left to it ſelf, will proceed on in one continued ſtraight line.

22. IF EN be taken equal to HM and NM be drawn; ſince HM is equidiſtant from EN, NM will be equidiſtant from EH. Therefore the effect of any power upon a moving body, when that power acts obliquely to the motion of the body, is to be determined in this manner. Suppoſe the body is moving along the ſtraight line AEB, if when the body is come to E, a power gives it an impulſe in the direction of the line EG, to find what courſe the body will afterwards take we muſt proceed thus. Take in EB any length EH, and in EG take ſuch a length EN, that if the body had been at reſt in E, the power applied to it would have cauſed it to move over EN in the ſame ſpace of time, as it would have employed in paſſing over EH, if the power had not acted at all upon it. Then draw HL equidiſtant from EG, and NM equidiſtant

from EB. After this, if a line be drawn from E to the point M, where theſe two lines meet, the line EM will be the courſe into which the body will be put by the action of the power upon it at E.

23. A MATHEMATICAL reader would here expect in ſome particulars more regular demonſtrations; but as I do not at preſent addreſs my ſelf to ſuch, ſo I hope, what I have now written will render my meaning evident enough to thoſe, who are unacquainted with that kind of reaſoning.

24. NOW as we have been ſhewing, that ſome actual force is neceſſary either to put bodies out of a ſtate of reſt into motion, or to change the motion, which they have once received; it is proper here to obſerve, that this quality in bodies, whereby they preſerve their preſent ſtate, with regard to motion or reſt, till ſome active force diſturb them, is called the VIS INERTIAE of matter: and by this property, matter, ſluggiſh and unactive of it ſelf, retains all the power impreſſed upon it, and cannot be made to ceaſe from action, but by the oppoſition of as great a power, as that which firſt moved it. By the degree of this VIS INERTIAE, or power of inactivity, as we ſhall henceforth call it, we primarily judge of the quantity of ſolid matter in each body; for as this quality is inherent in all the bodies, upon which we can make any trial, we conclude it to be a property eſſential to all matter; and as we yet know no reaſon to ſuppoſe, that bodies are compoſed of different kinds of matter, we rather preſume, that the matter of all bodies is the ſame; and that the degree of this

this power of inactivity is in every body proportional to the quantity of the ſolid matter in it. But although we have no abſolute proof, that all the matter in the univerſe is uniform, and poſſeſſes this power of inactivity in the ſame degree; yet we can with certainty compare together the different degrees of this power of inactivity in different bodies. Particularly this power is proportional to the weight of bodies, as Sir ISAAC NEWTON has demonſtrated [a]. However, notwithſtanding that this power of inactivity in any body can be more certainly known, than the quantity of ſolid matter in it; yet ſince there is no reaſon to ſuſpect that one is not proportional to the other, we ſhall hereafter ſpeak without heſitation of the quantity of matter in bodies, as the meaſure of the degree of their power of inactivity.

25. THIS being eſtabliſhed, we may now compare the effects of the ſame power upon different bodies, as hitherto we have ſhewn the effects of different powers upon the ſame body. And here if we limit the word motion to the peculiar ſenſe given to it in philoſophy, we may comprehend all that is to be ſaid upon this head under one ſhort precept; that the ſame power, to whatever body it is applied, will always produce the ſame degree of motion. But here motion does not ſignify the degree of celerity or velocity with which a body moves, in which ſenſe only we have hitherto uſed it; but it is made uſe of particularly in philoſophy to ſignify the force with which a body moves: as if two bodies A and B be-

[a] Princ. Philoſ. L. II. prop. 24. corol. 7. See alſo B. II. Ch. 5. § 3. of this treatiſe.

ing in motion, twice the force would be required to ſtop A as to ſtop B, the motion of A would be eſteemed double the motion of B. In moving bodies, theſe two things are carefully to be diſtinguiſhed; their velocity or celerity, which is meaſured by the ſpace they paſs through during any determinate portion of time; and the quantity of their motion, or the force, with which they will preſs againſt any reſiſtance. Which force, when different bodies move with the ſame velocity, is proportional to the quantity of ſolid matter in the bodies; but if the bodies are equal, this force is proportional to their reſpective velocities, and in other caſes it is proportional both to the quantity of ſolid matter in the body, and alſo to its velocity. To inſtance in two bodies A and B: if A be twice as great as B, and they have both the ſame velocity, the motion of A ſhall be double the motion of B; and if the bodies be equal, and the velocity of A be twice that of B, the motion of A ſhall likewiſe be double that of B; but if A be twice as large as B, and move twice as ſwift, the motion of A will be four times the motion of B; and laſtly, if A be twice as large as B, and move but half as faſt, the degree of their motion ſhall be the ſame.

26. THIS is the particular ſenſe given to the word motion by philoſophers, and in this ſenſe of the word the ſame power always produces the ſame quantity or degree of motion. If the ſame power act upon two bodies A and B, the velocities, it ſhall give to each of them, ſhall be ſo adjuſted to the reſpective bodies, that the ſame degree of motion ſhall be produced in each. If A be twice as great as B, its velocity ſhall be half

that

that of B; if A has three times as much ſolid matter as B, the velocity of A ſhall be one third of the velocity of B; and generally the velocity given to A ſhall bear the ſame proportion to the velocity given to B, as the quantity of ſolid matter contained in the body B bears to the quantity of ſolid matter contained in A.

27. THE reaſon of all this is evident from what has gone before. If a power were applied to B, which ſhould bear the ſame proportion to the power applied to A, as the body B bears to A, the bodies B and A would both receive the ſame velocity; and the velocity, which B will receive from this power, will bear the ſame proportion to the velocity, which it would receive from the action of the power applied to A, as the former of theſe powers bears to the latter: that is, the velocity, which A receives from the power applied to it, will bear to the velocity, which B would receive from the ſame power, the ſame proportion as the body B bears to A.

28. FROM hence we may now paſs to the third law of motion, where this diſtinction between the velocity of a body and its whole motion is farther neceſſary to be regarded, as ſhall immediately be ſhewn; after having firſt illuſtrated the meaning of this law by a familiar inſtance. If a ſtone or other load be drawn by a horſe; the load re-acts upon the horſe, as much as the horſe acts upon the load; for the harneſs, which is ſtrained between them, preſſes againſt the horſe as much as againſt the load; and the progreſſive motion of the horſe

horſe forward is hindred as much by the load, as the motion of the load is promoted by the endeavour of the horſe: that is, if the horſe put forth the ſame ſtrength, when looſened from the load, he would move himſelf forwards with greater ſwiftneſs in proportion to the difference between the weight of his own body and the weight of himſelf and load together.

29. THIS inſtance will afford ſome general notion of the meaning of this law. But to proceed to a more philoſophical explication: if a body in motion ſtrike againſt another at reſt, let the body ſtriking be ever ſo ſmall, yet ſhall it communicate ſome degree of motion to the body it ſtrikes againſt, though the leſs that body be in compariſon of that it impinges upon, and the leſs the velocity is, with which it moves, the ſmaller will be the motion communicated. But whatever degree of motion it gives to the reſting body, the ſame it ſhall loſe it ſelf. This is the neceſſary conſequence of the forementioned power of inactivity in matter. For ſuppoſe the two bodies equal, it is evident from the time they meet, both the bodies are to be moved by the ſingle motion of the firſt; therefore the body in motion by means of its power of inactivity retaining the motion firſt given it, ſtrikes upon the other with the ſame force, wherewith it was acted upon it ſelf: but now both the bodies being to be moved by that force, which before moved one only, the enſuing velocity will be the ſame, as if the power, which was applied to one of the bodies, and put it into motion, had been applied to both; whence it appears, that they will proceed forwards,

with half the velocity, which the body firſt in motion had: that is, the body firſt moved will have loſt half its motion, and the other will have gained exactly as much. This rule is juſt, provided the bodies keep contiguous after meeting; as they would always do, if it were not for a certain cauſe that often intervenes, and which muſt now be explained. Bodies upon ſtriking againſt each other, ſuffer an alteration in their figure, having their parts preſſed inwards by the ſtroke, which for the moſt part recoil again afterwards, the bodies endeavouring to recover their former ſhape. This power, whereby bodies are inabled to regain their firſt figure, is uſually called their elaſticity, and when it acts, it forces the bodies from each other, and cauſes them to ſeparate. Now the effect of this elaſticity in the preſent caſe is ſuch, that if the bodies are perfectly elaſtic, ſo as to recoil with as great a force as they are bent with, that they recover their figure in the ſame ſpace of time, as has been taken up in the alteration made in it by their compreſſion together; then this power will ſeparate the bodies as ſwiftly, as they before approached, and acting upon both equally, upon the body firſt in motion contrary to the direction in which it moves, and upon the other as much in the direction of its motion, it will take from the firſt, and add to the other equal degrees of velocity: ſo that the power being ſtrong enough to ſeparate them with as great a velocity, as they approached with, the firſt will be quite ſtopt, and that which was at reſt, will receive all the motion of the other. If the bodies are elaſtic in a leſs degree, the firſt will not loſe all its motion, nor will the other acquire the motion of the firſt, but fall as much ſhort of it, as the other retains.

For

For this rule is never deviated from, that though the degree of elaſticity determines how much more than half its velocity the body firſt in motion ſhall loſe; yet in every caſe the loſs in the motion of this body ſhall be transferred to the other, that other body always receiving by the ſtroke as much motion, as is taken from the firſt.

30. THIS is the caſe of a body ſtriking directly againſt an equal body at reſt, and the reaſoning here uſed is fully confirmed by experience. There are many other caſes of bodies impinging againſt one another: but the mention of theſe ſhall be reſerved to the next chapter, where we intend to be more particular and diffuſive in the proof of theſe laws of motion, than we have been here.

CHAP. II.

Farther proofs of the LAWS of MOTION.

HAVING in the preceding chapter deduced the three laws of motion, delivered by our great philoſopher, from the moſt obvious obſervations, that ſuggeſt them to us; I now intend to give more particular proofs of them, by recounting ſome of the diſcoveries which have been made in philoſophy before Sir ISAAC NEWTON. For as they were all collected by reaſoning upon thoſe laws; ſo the conformity of theſe diſcoveries to experience makes them ſo many proofs of the truth of the principles, from which they were derived.

2. LET

2. LET us begin with the ſubject, which concluded the laſt chapter. Although the body in motion be not equal to the body at reſt, on which it ſtrikes; yet the motion after the ſtroke is to be eſtimated in the ſame manner as above. Let A (in fig. 3.) be a body in motion towards another body B lying at reſt. When A is arrived at B, it cannot proceed farther without putting B into motion; and what motion it gives to B, it muſt loſe it ſelf, that the whole degree of motion of A and B together, if neither of the bodies be elaſtic, ſhall be equal, after the meeting of the bodies, to the ſingle motion of A before the ſtroke. Therefore, from what has been ſaid above, it is manifeſt, that as ſoon as the two bodies are met, they will move on together with a velocity, which will bear the ſame proportion to the original velocity of A, as the body A bears to the ſum of both the bodies.

3. IF the bodies are elaſtic, ſo that they ſhall ſeparate after the ſtroke, A muſt loſe a greater part of its motion, and the ſubſequent motion of B will be augmented by this elaſticity, as much as the motion of A is diminiſhed by it. The elaſticity acting equally between both the bodies, it will communicate to each the ſame degree of motion; that is, it will ſeparate the bodies by taking from the body A and adding to the body B different degrees of velocity, ſo proportioned to their reſpective quantities of matter, that the degree of motion, wherewith A ſeparates from B, ſhall be equal to the degree of motion, wherewith B ſeparates from A. It follows therefore, that the velocity taken from A by the elaſticity bears to the velocity, which the ſame elaſticity adds to B, the

ſame proportion, as B bears to A: conſequently the velocity, which the elaſticity takes from A, will bear the ſame proportion to the whole velocity, wherewith this elaſticity cauſes the two bodies to ſeparate from each other, as the body B bears to the ſum of the two bodies A and B; and the velocity, which is added to B by the elaſticity, bears to the velocity, wherewith the bodies ſeparate, the ſame proportion, as the body A bears to the ſum of the two bodies A and B. Thus is found, how much the elaſticity takes from the velocity of A, and adds to the velocity of B; provided the degree of elaſticity is known, whereby to determine the whole velocity wherewith the bodies ſeparate from each other after the ſtroke [a].

4. AFTER this manner is determined in every caſe the reſult of a body in motion ſtriking againſt another at reſt. The ſame principles will alſo determine the effects, when both bodies are in motion.

5. LET two equal bodies move againſt each other with equal ſwiftneſs. Then the force, with which each of them preſſes forwards, being equal when they ſtrike; each preſſing in its own direction with the ſame energy, neither ſhall ſurmount the other, but both be ſtopt, if they be not elaſtic: for if they be elaſtic, they ſhall from thence recover new motion, and recede from each other, as ſwiftly as they met, if they be perfectly elaſtic; but more ſlowly, if leſs ſo. In the ſame manner, if two bodies of unequal bigneſs ſtrike againſt each other, and their velocities be ſo related, that the velocity

[a] How this degree of elaſticity is to be found by experiment, will be ſhewn below in § 74.

of

of the leſſer body ſhall exceed the velocity of the greater in the ſame proportion, as the greater body exceeds the leſſer (for inſtance, if one body contains twice the ſolid matter as the other, and moves but half as faſt) two ſuch bodies will entirely ſuppreſs each other's motion, and remain from the time of their meeting fixed; if, as before, they are not elaſtic: but, if they are ſo in the higheſt degree, they ſhall recede again, each with the ſame velocity, wherewith they met. For this elaſtic power, as in the preceding caſe, ſhall renew their motion, and preſſing equally upon both, ſhall give the ſame motion to both; that is, ſhall cauſe the velocity, which the leſſer body receives, to bear the ſame proportion to the velocity, which the greater receives, as the greater body bears to the leſſer: ſo that the velocities ſhall bear the ſame proportion to each other after the ſtroke, as before. Therefore if the bodies, by being perfectly elaſtic, have the ſum of their velocities after the ſtroke equal to the ſum of their velocities before the ſtroke, each body after the ſtroke will receive its firſt velocity. And the ſame proportion will hold likewiſe between the velocities, wherewith they go off, though they are elaſtic but in a leſs degree; only then the velocity of each will be leſs in proportion to the defect of elaſticity.

6. IF the velocities, wherewith the bodies meet, are not in the proportion here ſuppoſed; but if one of the bodies, as A, has a ſwifter velocity in compariſon to the velocity of the other; then the effect of this exceſs of velocity in the body A muſt be joined to the effect now mentioned, after the manner of this following example. Let A be twice as great as B, and

move with the ſame ſwiftneſs as B. Here A moves with twice that degree of ſwiftneſs, which would anſwer to the forementioned proportion. For A being double to B, if it moved but with half the ſwiftneſs, wherewith B advances, it has been juſt now ſhewn, that the two bodies upon meeting would ſtop, if they were not elaſtic; and if they were elaſtic, that they would each recoil, ſo as to cauſe A to return with half the velocity, wherewith B would return. But it is evident from hence, that B by encountring A will annul half its velocity, if the bodies be not elaſtic; and the future motion of the bodies will be the ſame, as if A had advanced againſt B at reſt with half the velocity here aſſigned to it. If the bodies be elaſtic, the velocity of A and B after the ſtroke may be thus diſcovered. As the two bodies advance againſt each other, the velocity, with which they meet, is made up of the velocities of both bodies added together. After the ſtroke their elaſticity will ſeparate them again. The degree of elaſticity will determine what proportion the velocity, wherewith they ſeparate, muſt bear to that, wherewith they meet. Divide this velocity, with which the bodies ſeparate into two parts, that one of the parts bear to the other the ſame proportion, as the body A bears to B; and aſcribe the leſſer part to the greater body A, and the greater part of the velocity to the leſſer body B. Then take the part aſcribed to A from the common velocity, which A and B would have had after the ſtroke, if they had not been elaſtic; and add the part aſcribed to B to the ſame common velocity. By this means the true velocities of A and B after the ſtroke will be made known.

7. IF

7. IF the bodies are perfectly elaſtic, the great HUYGENS has laid down this rule for finding their motion after concourſe[a]. Any ſtraight line CD (in fig. 4, 5.) being drawn, let it be divided in E, that CE bear the ſame proportion to ED, as the ſwiftneſs of A bore to the ſwiftneſs of B before the ſtroke. Let the ſame line CD be alſo divided in F, that CF bear the ſame proportion to FD, as the body B bears to the body A. Then FG being taken equal to FE, if the point G falls within the line CD, both the bodies ſhall recoil after the ſtroke, and the velocity, wherewith the body A ſhall return, will bear the ſame proportion to the velocity, wherewith B ſhall return, as GC bears to GD; but if the point G falls without the line CD, then the bodies after their concourſe ſhall both proceed to move the ſame way, and the velocity of A ſhall bear to the velocity of B the ſame proportion, that GC bears to GD, as before.

8. IF the body B had ſtood ſtill, and received the impulſe of the other body A upon it; the effect has been already explained in the caſe, when the bodies are not elaſtic. And when they are elaſtic, the reſult of their colliſion is found by combining the effect of the elaſticity with the other effect, in the ſame manner as in the laſt caſe.

9. WHEN the bodies are perfectly elaſtic, the rule of HUYGENS[b] here is to divide the line CD (fig. 6.) in E as before, and to take EG equal to ED. And by theſe points

[a] In oper. poſthum. de Motu corpor. ex percuſſion. prop. 9.

[b] In the above-cited place.

thus