Frictionless plane

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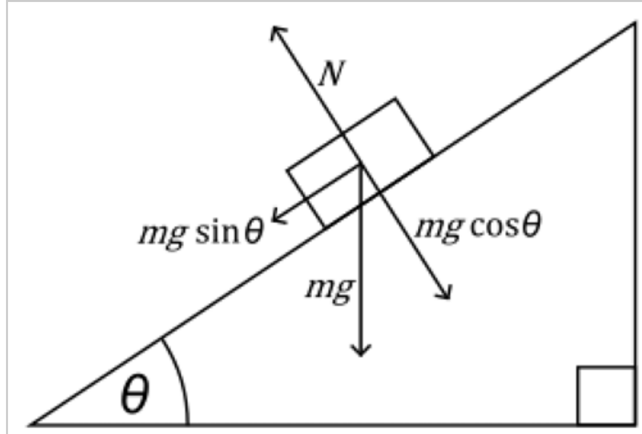

Key:
N = normal force that is perpendicular to the plane
m = mass of object
g = acceleration due to gravity
θ (theta) = angle of elevation of the plane, measured from the horizontal

The **frictionless plane** is a concept from the writings of Galileo Galilei. In his 1608 *The Two New Sciences*, Galileo presented a formula that predicted the motion of an object moving down an inclined plane. His formula was based upon his past experimentation with free-falling bodies.[1] However, his model was not based upon experimentation with objects moving down an inclined planes, but from his conceptual modeling of the forces acting upon the object. Galileo understood the mechanics of the inclined plane as the combination of horizontal and vertical vectors; the result of gravity acting upon the object, diverted by the slope of the plane. [2]

However, Galileo's equations do not contemplate friction, and therefore do not perfectly predict the results of an actual experiment. This is because some energy is always lost when one mass applies a non-zero normal force to another. Therefore, the observed speed, acceleration and distance traveled should be less than Galileo predicts. [3] This energy is lost in forms like sound and heat. However, from Galileo's predictions of an object moving down an inclined plane in a frictionless environment, he created the theoretical foundation for extremely fruitful real-world experimental prediction.[4]

There are no frictionless planes anywhere to be found; there, by definition, cannot be. However, if there were, one can be all but certain that objects on them would behave exactly as Galileo predicts. However illusory, their value in the design of engines, motors, roadways, even the design of tow truck beds to name a few examples, is noteworthy. [5]

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Effect of friction on Galilean predictions

Actual results from objects moving down inclined planes can be predicted very accurately by calculating the effect of friction upon the result predicted by Galileo. This is done with the simple formula F(fr)=μ(k/s)*F(n), where the force of friction is equal to the static or kinetic friction coefficient times the vertical normal force of the object against the plane.[6] Unless in a vacuum, a (usually) small amount of potential energy is also lost to air drag.

Other scientific applications

Similar conceptual tools are in constant use in the physical sciences. From string theory to cosmology, theories are proposed and predictions are made based upon assumption about the properties of objects that have never been observed. Many of these objects are far harder to imagine than inclined plane with a frictionless surface. John Dalton proposed the positive proton and negative electron structure of atoms almost a century before anyone had seen one, yet groundbreaking advances in chemistry, physics, and eventually quantum mechanics and quantum electrodynamics were only possible because of that postulate. Similarly, no one has directly observed dark energy or captured any quantity of dark matter. No one has observed a tiny string that was the indivisible foundation of all matter in the universe. Yet, theories that imagine such objects are not tautological; they entail predictions that can be, and have been, disproved. Thus, they serve as valuable tools in the human endeavor to understand the universe, despite the fact that they have not or cannot be found within it.

Non-scientific applications

Neither is the frictionless plane a concept unique to science. Many other fields have used conceptual understandings of problems with limited or no direct real-world applicability to great effect. Of particular note is a reference to Galileo's plane in Thomas Hobbes' *Leviathan*. In *Leviathan*, Hobbes begins by considering the condition of man in the state of nature; without government, without morals, without order. He famously describes the state of nature as the state of war, a state of all against all, where life was solitary, poor, nasty, brutish, and short. However, Hobbes makes clear that the justification for the government described in *Leviathan*, whose primary purpose is to keep man out of the state of nature, and from the corresponding fear of a violent death, does not depend upon man ever having lived in this condition. Instead, just like the frictionless plane, his description of the state of nature is valuable for how it informs humanity's current condition, not only for the accuracy of its description:

"But there is another saying not of late understood, by which they might learn truly to read one another, if they would take the pains; and that is, Nosce Teipsum, Read Thy Self: which was not meant, as it is now used, to countenance, either the barbarous state of men in power, towards their inferiors; or to encourage men of low degree, to a sawcie behaviour towards their betters; But to teach us, that for the similitude of the thoughts, and Passions of one man, to the thoughts, and Passions of another,whosoever looketh into himselfe, and considereth what he doth, when he does Think, Opine, Reason, Hope, Feare, &c, and upon what grounds; he shall thereby read and know, what are the thoughts, and Passions of all other men...for these the constitution individuall, and particular education do so vary, and they are so easie to be kept from our knowledge, that the characters of mans heart, blotted and confounded as they are, with dissembling, lying, counterfeiting, and erroneous doctrines, are legible onely to him that searcheth hearts. And though by mens actions wee do discover their designee sometimes; yet to do it without comparing them with our own, and distinguishing all circumstances, by which the case may come to be altered, is to decipher without a key, and be for the most part deceived." [7]

More recently, John Rawls, while very much disagreeing with Hobbes' conception of the state of nature, used this same methodology in describing an admittedly artificial original position from which his *Theory of Justice* derives.

Frictionless plane as a pragmatic methodology

Galileo died 40 years before Isaac Newton's *Philosophiae Naturalis Principia Mathematica* which described normal force (Newton's third law of motion), inertia (Newton's first law of motion), and most importantly, Newton's law of universal gravitation; he died nearly three centuries before Albert Einstein published his theory of general relativity. Nevertheless, by thinking about the forces (as he understood them) acting upon an object on an inclined plane, Galileo came to understand the mechanics of the situation in a very fundamental way. From that understanding, he was able to extrapolate the general formula.

At bottom, the frictionless plane is a method of understanding otherwise opaque phenomena to make them receptive to experimentation, and understanding. Galileo did not solve the inclined plane by performing experiments, considering the results, then attempting to reverse engineer a calculation that could accommodate those results. From what we now know, such an equation would have been incorrect, for any result is the combination of gravitational *and* frictional forces. Instead, he began thinking about how gravity works upon free-falling objects, and what about that force is the same, and what about it is different when an object moves down an inclined plane. It is this methodology that is so remarkable, and gives the frictionless plane its immense practical value.

References

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3. ^ Jenkin, Fleeming. *On Friction Between Surfaces at Low Speeds.* Proceedings of the Royal Society of London, Vol. 26 p. 93-94
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7. ^ Hobbes, Thomas *Leviathan*. Available at Project Gutenberg (http://www.gutenberg.org/dirs/etext02/lvthn10.txt)