

# **The God of Falling Bodies**

## **Galileo, Newton, Bentley, and Leibniz Chat on the Internet**

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*Here's what might transpire if Galileo were a modern-day experimentalist engaged in an e-mail dialogue on science and religion with two famous scientific colleagues and a theologian.*

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In order to explore some of the thinking processes involved in the current dialogue between science and religion, I have imagined the following fable. The characters in my fable are modern-day versions of Galileo, Newton, and Leibniz. Also included is the a lesser known historical figure, theologian Richard Bentley, with whom Newton corresponded. Galileo is pictured as a modern-day experimental physicist, performing increasingly precise experiments with falling bodies at the Leaning Tower of Pisa. I imagine him rapidly communicating his results by e-mail to Newton in Cambridge, who is contemporaneously developing his laws of motion and gravity. Of course, Galileo preceded the other characters by two generations, so this interchange is obviously not historical. Furthermore, although both men were brilliant theorists and experimentalists, I am going to impose a modern division of labor and have Galileo be strictly an experimentalist and Newton a theorist. Galileo will have the best modern equipment at his disposal, and I will imagine each as if he thought like a scientist of today, not one of the sixteenth and seventeenth centuries.

Bentley is pictured discussing Galileo's experimental results and their theological implications with Newton and Galileo over the Internet. I show Newton doing his best to explain the data by means of natural laws and, like typical modern theoretical physicists (that is, those who do not attempt to write popular books), not fretting too much about theology. While the historical Newton branched off into theology and alchemy, this was later in life. In my scenario he is still a typical (for today) young researcher, impatient with philosophizing and eager to get on with his work with minimum distraction.

Bentley seeks the God of the Gaps, looking for places where Newton's theories seem to leave room for the Creator to impose his will. He exhibits the general misunderstanding and resulting distrust of scientific method that typifies the modern intellectual, who is intelligent but lacks scientific training and, worse, has little comprehension of scientific method. Galileo expresses religious skepticism more openly than he could in his day, but would have no trouble getting away with today. Finally, Leibniz joins the discussion near the end. He represents the new crop of science-theists who, unlike Bentley, know their science and mathematics but still think they see God's hand in physics and cosmology,

In his initial, crude experiments, Galileo measures the times,  $t$ , that it takes cannonballs of various weights to drop from balconies in the tower at different heights  $h$ . He makes a graph of  $h$  vs.  $t$  and shows that the data fit a parabolic curve,  $h = kt^2$ , with  $k$  a constant equal to 4.9 when  $h$  is measured in meters and  $t$  in seconds.

When Newton sees these results he e-mails Bentley and Galileo:

“Dear Friends: This is exactly what is predicted by my laws of motion and gravity. My second law of motion is  $F = ma$ , where  $F$  is the force on a body,  $m$  is its mass, and  $a$  is its acceleration. Putting it together with my law of gravity gives  $a = g$ , where  $g = 9.8$  meters per second squared is the acceleration due to gravity, independent of the mass  $m$ . Using the methods of calculus, which I invented despite the claims of that upstart Leibniz, I then get  $h = kt^2$  where  $k = g/2 = 4.9$ .”

Bentley finds Newton’s explanation difficult to understand: “Isaac, as usual I do not have a clue what you are talking about :). It all seems rather magical to me. Why should this 'calculus' or yours, with all those strange symbols, have anything to do with reality?”

Newton responds, “Richard, I don’t know why, but it seems to. I frame no hypotheses. I just calculate and compare my calculations with the data.”

In the meantime, Galileo continues his experiments with objects other than cannonballs and discovers something new. He drops a crumpled up piece of paper, along with a rock. Releasing them at the same time from the same height, the paper hits the ground after the rock. A sheet of paper, and then a feather, taken even longer.

When Bentley sees this result he excitedly types:

“See, Isaac, your theory is incomplete. God is acting to hold up the paper and the feather. This explains how birds and angels fly! God wills it.

Galileo, who has been quiet so far except for supplying the data, butts in:

“I’ve never seen any angels, even with my telescope. But birds must fly by taking advantage of the upward force of the air, as da Vinci has suggested.”

Newton does not take long to respond: “In the original experiments, Galileo was dropping heavy objects--cannonballs. So I neglected the effect of air resistance, which I guessed would be small in that case.

“In general, however, the air is expected to exert an upward force that subtracts from the downward force of gravity, and this will be important for lighter objects. This resistive force depends on the velocity at which the body falls. I have modeled it as proportional to the square of the velocity and determined an air resistance coefficient from the data, which varies from object to object. Using some more calculus, I have obtained a fairly reasonable fit to Galileo’s data, as you can see by the attached graphs.”

Bentley is not too impressed: “That looks like a pretty ad hoc procedure to me. And so complicated! Only two people in the world can make such a calculation, Newton and Leibniz. Are we to rely on the authority of just the two of you? I prefer to rely on the authority of scriptures and the Church fathers. They provide a much simpler explanation that even the humblest peasant can understand, namely that God directs the motion of all things, from falling leaves to flying birds.”

Galileo is a bit annoyed: “I think I can manage this calculus too. After all, I am a professor of mathematics! But, more important, where in the God theory can you obtain the detailed, quantitative results Isaac has here? He can make all kind of predictions about falling bodies and projectiles. Even the Biblical prophets could not do that.”

“They were men of peace, not interested in bombs and cannonballs,” Bentley reverently but irrelevantly replies.

Things only get worse when Galileo reports another strange anomaly. His falling bodies do not hit the ground at a point directly below the release point, as marked precisely by a plumb bob, but slightly off to the east. He is careful to show that this is

not an effect of winds.

“Aha,” Bentley cries, when the data appear on the Web. “More evidence for God’s action.” The Creator is blowing the objects off to the east.

“Why would he do that?” Galileo questions.

“This is just one of those mysteries we were not meant to understand,” Bentley answers.

Newton scratches his head but soon realizes what is happening.

“My previous calculations assumed that the Earth is not accelerating. In fact, the rotation about its axis constitutes an acceleration. When I properly add this term to my equations, I get exactly what Galileo observes.”

“More ad hoc fixes and fudge factors,” Bentley retorts scathingly. “And look at those equations now. How complicated can they get? What purpose are you serving with all these esoteric symbols. It looks to me like you are starting a new cult, and you know what the Church thinks of cults!”

“Christianity was once a cult,” Galileo sourly answers.

Newton tries to cool things off. “Bentley, it is too bad you have not been able to follow my mathematics. (Damn these lousy schools.) If you could do the maths, you would see that my equations already contained the solutions to all the problems raised by Galileo’s increasingly more precise measurements. The “ $F$ ” in  $F = ma$  represents the sum of the forces on a body. The term I added for air resistance in retrospect should have been included all along. Similarly, the “ $a$ ” in  $F = ma$  must include the acceleration of the Earth. Putting in the correct acceleration we again get what Galileo measures. What happens in the present case is that, because it is farther from the center of the Earth, the body at its point of release has a greater eastward component of velocity than a point on the ground, and so it drifts to the east relative to that point. And here is a falsifiable prediction! If Galileo does experiments with cannon balls shot straight up in the air, they will drift to the west.”

Back in Italy, Galileo is presented with a huge grant from Cosimo de Medici, from which he purchases lasers and a highly accurate atomic clock. Repeating his experiments, he finds that, even after corrections for air resistance and the Earth’s rotation, the  $g$  in Newton’s equations is not a constant but depends on the height of the tower balcony from which objects are dropped.

Once again, Bentley goads Newton: “This surely proves that your theory is, at best, an approximation and so cannot be related in any important way to ‘ultimate reality.’ Each time our friend Galileo makes a better experiment, you have to modify your equations to make them agree with his data. What are you going to do now about this non-constant value of  $g$ ?”

“Well, if you could follow the maths you would see that this, too, is in my equations. When I conceived the law of gravity I realized it applies to objects far from the Earth, such as the Moon, as well as apples and leaves falling from trees. The Moon, in a sense, is falling toward the Earth like an apple; but, because of its speed in orbit, it falls around the Earth without ever hitting it. From estimates of the Moon’s distance and the time it takes to go around the Earth, one month, I was able to infer that the force of gravity, and thus the acceleration of a falling body, will decrease as the square of its distance to the center of the Earth. In fact, my law of gravity reads  $F = GmM/r^2$  as the force between two bodies of masses  $m$  and  $M$  whose centers of gravity are separated by a distance  $r$ , where  $G$  is a constant determined from the data.

“The resulting acceleration on a body of mass  $m$  toward the Earth is then  $g = GM/r^2$  where  $M$  is the mass of the Earth and  $r$  is the distance to the center. The variation with  $r$  is normally unmeasurable near the Earth’s surface, since the difference between  $r$  and the radius of the Earth  $R$  is small. So we are justified in neglecting it for most practical purposes. However, Galileo was able to detect the variation with his lasers and atomic clock.”

“If I can’t read your equations, neither can the great majority of the human race,” Bentley responds. “How are you ever going to convince them?”

Newton sighs. “OK, let me try to explain the significance of what I have done in words, which are unfortunately more imprecise than the maths. I have provided techniques that enable a sufficiently trained person to make quantitative calculations of precise measurements that agree with all the data. These equations also enable that person to make predictions about the motions of bodies that can be later tested by experiments. I hope Galileo and others will carry out these tests of my theories. My good friend Edmund Halley has just informed me that my equations predict that the recent comet will return again in 75 years. Unfortunately we will not be here to see if this prediction comes true. “Even if some of these predictions fail, this could simply mean that I have once again made too many simplifying assumptions in my calculation, as I did when originally neglecting air friction or the Earth’s rotation. The comet prediction should be an accurate one, however, since neither Halley nor I can think of any factors that may mess it up.

“Bentley, you have continually derided the fact that I did not anticipate some of Galileo’s measurements before they were made. But rather than taking this as a point against the validity of my theories, you should regard it as a point for!”

Bentley blinks. “Come again?”

“The fact that even I, the inventor of the theories, did not realize all their implications indicates, rather strongly I think, that they indeed have something to do with reality. In fact, you might say that I was not the inventor of the theories but rather their discoverer. They were out there in nature waiting for someone brilliant like me to come along to find them. “Let me contrast my theories with yours, dear Bentley, that God has done it all. You claim your theory is simpler, and so more preferable, more likely to be correct than my complicated calculus equations.

“But is it simpler? I have been able to classify a large range of phenomena, on Earth and in the heavens, with a few assumptions that are very simple in their own right. The complications you worry about are only in the manipulations, which admittedly require some inborn talent comparable to playing a musical instrument well.”

Galileo then jumps in with a thought: “Perhaps, someday, humans will possess machines that will do these calculations for them. Then all they will have to do is put in the initial positions and velocities, and predict the future motion of all bodies. If Lucretius is correct—that everything is made up of atoms—then everything will be predictable.”

Suddenly, Bentley breaks out into a broad grin and excitedly types: “Even if you are correct, and everything that happens in the universe can ultimately be predicted by some huge machine, the hand of the Creator was still involved. You have just written down some esoteric equations, but you have not told me where those equations come from. I think it is all pretty obvious. They came from God!”

“Why did they have to come from anything?,” Galileo interjects,

“Everything comes from something.”

“And God, where did he come from?”

“Well, God is the exception. As Aquinas said, the first cause uncaused.”

“Why can’t that exception be the universe itself?”

Bentley does not answer, since he has become troubled by another thought: “I don’t think I like this idea after all. What happens to free will?”

“I will leave it to you theologians to figure that one out,” Galileo responds.

Newton has not said much for a while and now speaks up: “Actually, now that you have distracted me from my research and dragged me into a theological discussion, I must admit that my theory does not account for everything. Remember I said that my law of gravity does not give the value of  $G$ . I have to get that from the data. Also, recall that the Moon is like a falling object. My equations will tell you that the Moon’s orbit around the Earth is elliptical, but they do not give the orientation of the axes of the ellipse.”

“Ah, better yet!” Bentley exclaims. “We are back exactly to the God of the Bible. He creates the universe with its matter and light. He commands this matter and light to obey certain natural laws, which you scientists are now beginning to discover. But the Creator sees to it that the laws do not preordain all that happens. Humans then have the free will to act, from which we get evil despite God’s innate goodness. All this freedom, however, can lead to things getting out of hand. So, God acts whenever necessary to keep the universe and mankind moving on track toward the ultimate realization of his divine plan.”

Just then an e-mail comes in from Leibniz in Germany:

“I just happened to get wind of this discussion while surfing the Web. I have looked at Newton’s equations on his Web page and can confirm that they fit Galileo’s data. In fact, I did invent calculus independently and used my own methods which I think are superior, especially in terms of notation.”

Newton: “Balderdash!”

“In any case,” Leibniz continues, “I have to go along with Bentley that God’s purpose is evident in all that is being uncovered here. Let’s take Newton’s constant  $G$  in his theory of gravity. He admits that his theory does not give its value, that it must be determined by experiment. I am sure that Bentley will agree that it must be set by God.”

Bentley responds, “Indubitably.”

“But I have more,” Leibniz types. “I think I can prove that God has set this value of  $G$  very precisely for the divine purpose of making human life possible. Newton’s equations, which I truly do admire despite their lamentable notation, have allowed me to calculate, with my own better methods, the effect that different values of  $G$  would have on the orbit Earth. Earth might have been farther from the Sun and too cold for life, or closer to the Sun and too hot.”

Newton replies, “Yes, yes. This is just the  $r^3/T^2 = a \text{ constant}$  law discovered observationally by Kepler which I have already proven from my theory. Note that if  $G$  were different we could have the same orbital radius  $r$  as now with just a different orbital period  $T$ .”

“I agree,” says Leibniz. “But with all the values of  $r$  and  $G$  to choose from, how unlikely it is that a random selection would have given just the right values we need for

our existence? Suppose we had a world in which a year was not 365 days. I shudder to think of what this would do to the seasons. I would wager that human life would again be impossible. As far as I can see, only the exact value of  $G$ , and the specific values of  $r$  and  $T$  we have, would allow for human life. God has obviously chosen these numbers carefully and created this as the best of all possible worlds."

"Or, the worst," Galileo replies. "it could all be just on, big accident."

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