The concept of kinetic energy was born in a raging dispute fueled by ego, sex, nationalistic zeal, and religious fervor. It is perhaps not surprising that the more general conservation of energy took a long time to establish. Energy can take many forms: mechanical, heat, electrical. It took centuries to explore the relationship between all these forms.

But it’s hard to understand how a concept like kinetic energy could be controversial. Today we know that collisions always conserve momentum $m v$, a vector quantity. In elastic collisions, the kinetic energy $\frac{1}{2} m v^2$ is also conserved. In inelastic collisions, one or both of the colliding objects is broken, smashed, or otherwise deformed and, consequently, some of the kinetic energy is lost. So a few games of billiards ought to clear things up – right? Not with the following people involved:

**René Descartes** (1596-1650) was the first to propose that *something* is conserved in collisions: $m v$ (mass times scalar speed $v$). This quantity is like momentum, but it is a scalar. His argument was that the motion was transferred upon collision from one body to another.

**Gottfried Leibniz** (1646-1716) claimed that $m v^2$ was conserved in collisions, rather than Descartes’ $m v$. He called this quantity *vis viva*, Latin for “living force.” His idea was that the collision transfers *vis viva* from one object to another, giving it a kind of “life” by putting it in motion.

**Christiaan Huygens** (1629-1695) pointed out that the vector quantity $m v$ was conserved in collisions of hard spherical bodies. For such collisions, he showed that Leibniz’s *vis viva* $m v^2$ is also conserved. Collisions of hard particles are what we would now call “elastic.”

**Isaac Newton** (1643-1727) proved that $m v$ was the conserved quantity in collisions (and conserved in general). He argued against *vis viva* conservation because it could not account for inelastic collisions.

**Johann Bernoulli** (1667-1748) used Newton’s mechanics to show that $m v^2$ changes only when work is done on the object by a force. He argued that the difference between elastic and inelastic collisions had to do with the nature of the forces that arose in the collision.

**Emilie du Châtelet** (1706-1749) combined the ideas of Newton and Leibniz with experiments to support of the *vis viva* concept.

**Joseph-Louis Lagrange** (1736-1813) formulated a rigorous theory of analytical mechanics in 1788. He basically settled the *vis viva* controversy.

In an ideal world the problem would have ended many times, particularly with the “slam-dunks” by Huygens and Bernoulli. It’s interesting to see why it didn’t.
This case study is based on the following:

Before moving on, we emphasize that Huygens had essentially proven that a quantity proportional to $v^2$ is conserved in collisions prior to Newton’s work, although it was published later [1]. Huygens laid out four key principles of collisions. First, he pointed out that the “quantity of motion” $mv$ was conserved, in that the sum of the momenta of the colliding objects was the same before and after the collision. Huygens' second statement was that the sum of mass times velocity squared is conserved. The total kinetic energy is today represented by a half this amount, but the 1/2 is only really needed when discussing the general conservation of energy. His third principle is that an object will transfer more momentum to another if there is an object between them. His fourth is that the center of mass for a set of objects will move uniformly. He could only be sure about sets of spherical bodies for the fourth statement, but he did suggest that it was probably true in general.

Q1. Are Huygens's principles correct? How could we test them? Are there any disparities between these principles and our modern laws?

As with other arguments of the time, the dispute was more in the realm of philosophy and semantics than it was strictly scientific. The algebraic definition of physical quantities was seldom employed in papers, despite the revolutionary mathematical character of a lot of this work. Emphasis was often placed on what “force” actually meant, but different authors used the word force to mean different physical quantities. It is too easy today to apply our notions of force, energy, and momentum. Huygens was correct, but the debate went on for ages before that was realized.
Religion and Science in the *Vis Viva* Controversy

Newton was a devoutly religious individual. While he believed that the motion of the planets and stars followed mechanics and the law of gravity, he strongly felt that God was the driving force at the center of it all [2].

Newton’s idea that momentum was conserved, but not energy, played nicely into this picture, as we now explain. First think of ping-pong balls flying around randomly in a box, colliding with one another. If energy is conserved, they will keep bouncing around indefinitely. Now imagine the balls are "sticky". Since only momentum is conserved, all the balls will eventually come to a stop.

Now imagine all the stars in the universe flying through space like ping pong balls. Over time, a given star will eventually approach another star. The pull of that star’s gravity will change our star’s path. Over the eons, all stars will suffer many such collisions. If energy is not conserved, the universe will collapse over time into a single blob. An outside agent is needed to pour energy back in at a steady rate. In Newton’s view, that agent is God. The fact that the universe has shown no sign of collapsing is evidence of God’s existence.

Leibniz didn’t like the idea that miracles would continuously be needed to sustain the universe. He realized that the conservation of energy would force the stars to also transfer their motion to one another each time they interacted. This would allow the universe to run eternally without God’s constant intervention. In Leibniz’s view, conservation of *vis viva* (kinetic energy) was indeed the “force” that keeps the universe alive.

The “Natural Law” philosophy of Newton and others caught on with many English thinkers of the time. Newton’s brilliant innovations in science had made him an international star. Therefore, energy conservation was seen as an assault on theology. *Vis viva* in particular was seen as an occult or mystical phenomenon. Today we think of kinetic energy as a consequence of an object’s motion. Back then, however, *vis viva* was thought of as an intangible “fluid” that passes from one body to another when they touch. This seemed really weird.

The bitter personal rivalry between Newton and Leibniz did not help things. Both men had independently invented forms of the Calculus, and there was a nasty dispute of priority. It did not help that Leibniz was German and Newton English. Claims of plagiarism were hurled across national boarders. In England, Leibniz’s reputation was that of a mystical heretic.

Q2. How does the Newtonian view of the universe fit in to the scientific method? [Can you devise experiments or observations that address its “miraculous” aspects?]

Q3. How does Leibniz’s view of *vis viva* fit into the scientific method?

Q4. Do the religious and philosophical motivations strengthen or weaken either argument?
Science and the Public

The French were the referees in the Vis Viva dispute in some respects [3]. But they had their own claim: Descartes had essentially invented the problem. In the future, Lagrange would drive a stake in the heart of the dispute with his rigorous and mathematically complete formulation of analytical mechanics. But in the meantime, the controversy would continue to rise from the dead.

In 1724 the Paris Academy posed an essay competition concerning the collision of hard objects. Many were not satisfied with Huygen’s formulation, because they questioned whether such hard objects existed in the real world. The eminent Swiss mathematician Johann Bernoulli took up the challenge. Equipped with Leibniz’s formulation of differential calculus (the form we use today) and Newton’s mechanics, he showed that both momentum and vis viva, mv^2, were conserved. He further argued that the objects did not need to be perfectly rigid, by analogy to the collision of two springs. During the collision, the springs would first compress and then decompress, ending up with the same mv^2 they would have had they been point particles.

Bernoulli’s stated aim was to convince the Parisians that Leibnizian dynamics was correct, even if the underlying metaphysical argument (i.e., the weird “fluid”) was unfounded. He found strong opposition, largely by academicians that were not equipped to handle the mathematics. They did not understand why any aspect of an objects motion would be proportional to the square of the velocity – what effect of the velocity would be taken twice?

While Bernoulli argued that v^2 was plausible (see the Appendix), his non-mathematical opponents argued that all this math lacked “truthiness.” The argument raged for ten years, petering out as the combatants aged. Bernoulli’s mathematical peers accepted his arguments. Indeed, we teach them in physics classes today.

But in those days, science was not a business limited to trained experts. To the contrary, Aristocrats and others in the educated public followed and even took part these arguments. It was “cool” to like science. Newton’s Natural Law philosophy held sway, and Bernoulli was seen as a “Leibnizian mystic.” Furthermore, the rising French notions of freedom and equality emboldened many to disregard Bernoulli’s mathematics as mumbo jumbo from an effete elitist. However, Bernoulli did not have to deal with those people in the academy, so he felt that he had won. Nevertheless, feelings against vis viva would never disappear among the Eighteenth-century general public.

A case in point was the celebrated writer Voltaire, who was a passionate advocate of the rights of Man. While he had no real scientific education, he vigorously supported Natural Law, ridiculing Leibniz by parody in his famous Candide (Prof. Pangloss is Leibniz). He often discussed these issues with his mistress Emilie du Châtelet, and this lead to trouble.

Q5. How is this debate similar to the public debate over evolution?
Women in Science

Emilie du Châtelet had no formal scientific training, but unlike Voltaire, she understood better the value of mathematics [4]. As an Aristocrat, she acquired tutors and delved into the more technical scientific literature. She also studied the more philosophical writings of Leibniz, which had been dismissed by her peers (not to mention Voltaire). She was interested by Leibniz's arguments, but found little real proof. She tried to flesh out his ideas by performing her own experiments, but without success. Eventually, she uncovered experimental work by Willem 'sGravesande of the Netherlands, who had devised the key demonstration. He dropped weights into a block of clay and determined the effect of the speed of the weights on the depth they sunk into the clay. A simple relationship was found: the depth was proportional to the square of the speed.

Du Châtelet was able to combine the experiment with the theory, and published her ideas in the form of a textbook for children. This was the only avenue open to her, as she was not recognized by the academe. Unfortunately she did not live long past this publication, dying in her early 40s from complications due to childbirth.

Q6. Du Châtelet did not perform the weight-dropping experiment herself, but did publish work laying out all of the evidence for vis viva. How much credit can be given to her in this case?

Her premature death was the last of many setbacks she experienced as a woman. She was not able to study science or math despite her wealth, except through private instruction. Even after becoming knowledgeable through her own study, she had to fund her own private lab. When she made compelling arguments for vis viva and the conservation of energy, she was ignored and ridiculed. One of her tutors took credit for her work. Even Voltaire, her partner in science and other pursuits, dismissed vis viva was an occult belief, ridiculing her interest in his own writings. These accusations were taken at face value by the male establishment, and she was never taken seriously during her lifetime.

Q7. How much more could du Châtelet have expected as a man? What does it take for a scientist to succeed?

She did publish many scientific works, including the first French translation of Newton's famous *Principia Mathematica*. Voltaire said that her only fault was being born a woman, perhaps meaning it as a compliment. We can give him the benefit of the doubt considering their long-term affair. Others were much less charitable.

Q8. How great a barrier was sexism in the 18th century? What other barriers did she face? What advantages did she have?

Q9. Though she was not trying to suppress Newton, she was still working against an aspect of his thought. What sort of opposition would she face in this? How likely is the scientific community to change its mind in the face of new evidence? Was science rigorous enough at this point to establish a consensus? Is this different today? (Try writing a paper proving Einstein wrong!)
Appendix: Bernoulli’s argument for $v^2$

Bernoulli used geometry to show that the amount of work done by a moving body is proportional to the square of the velocity. The only knowledge needed is the Pythagorean theorem. Imagine an object traveling with velocity 1 that has just enough energy to compresses a spring. Now imagine the object travels with velocity 2. This can be resolved into a component with velocity 1 and $\sqrt{3}$. The velocity 1 component will be absorbed into a properly-aligned spring and the object will now continue with velocity $\sqrt{3}$. Another such process will leave $\sqrt{2}$, and another, 1. The object will come to rest after compressing its fourth spring. Thus the object has expended four times the energy with only twice the velocity. A similar example can be shown with velocity 3, 4, and so on.

Try this out on a piece of paper!