The motion of falling bodies

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A puzzle

When I was in school in M4, I was told that for a thousand years in Europe and elsewhere, the best minds of the age failed to understand projectile motion (what happens when you throw heavy things). Why? I can show M4 that now in five minutes. The reason was supposed to be that they followed Aristotle, but that can't be right. M4 knows that Aristotle was talking nonsense without being told. There were in fact many reasons, one of which we will explore below.

Before there was King in Thailand …

Try to imagine a life without cars, telephones, electricity, schools, pencils or paper in Europe a thousand years ago. They used Roman numerals and couldn't calculate ratios. If you had been living at that time and you had thought about motion at all, you would have been confused, as they were. Clear thinking requires language: definitions, structure and diagrams. They had no graphs and they had no algebra.

Nicole Oresme of Bayeux

As far as we know the first diagrams in two dimensions (graphs) were drawn by a French priest, Nicole Oresme (pronounced *Orem*) who was grand master of the College of Navarre in 1362, and by 1377 was Bishop of Liseux. He was a long-term personal friend of the Dauphin (Crown prince of France) who became Charles V and a very clever man who translated works of Aristotle from Latin to French.

Orem (*we shall use an English spelling of his name)* drew diagrams on a horizontal line (*for extension*) with vertical lines (*for intensity*). We have no record of anyone anywhere having done that before. We have drawn a diagram, like Orem did in his books, to show the increasing temperature along a metal bar heated at the right-hand end.

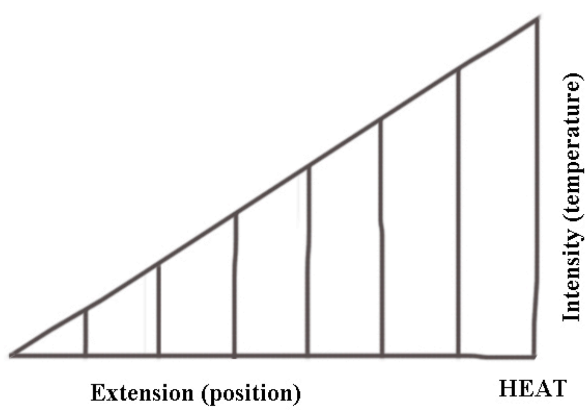

Fig 1 – a diagram in the style drawn by *Orem* around 1350.

The diagram in figure 1 has position on the horizontal line and the changing temperature as vertical lines. The change in temperature is uniform with respect to position and the diagram is a triangle. In modern terms we *plot a graph* of temperature against position in Logger Pro.

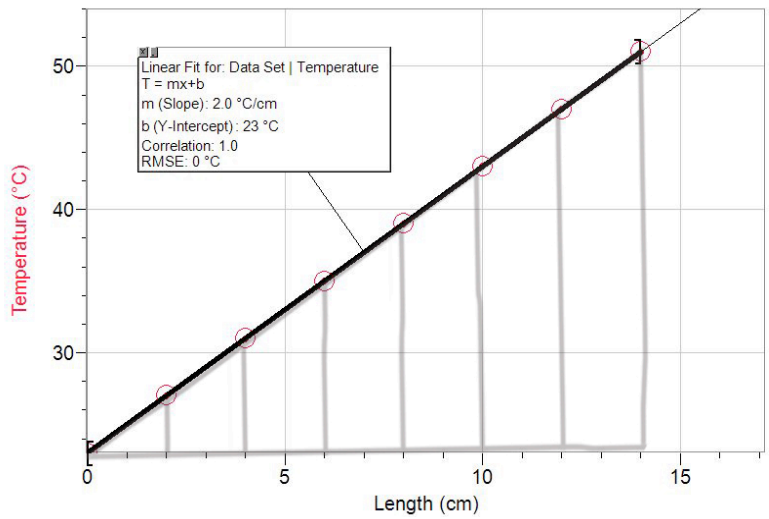

Fig 2 – a modern linear graph of temperature against position with an Orem-style diagram superimposed.

Orem made no measurements. To him any variable could be drawn as vertical lines. For example: he drew pain with vertical lines to represent intensity and drew time on the horizontal line. He went further. When the area under an intense pain for a short time was the same as the area under a lesser pain for a longer time he defined the “measure” of the two pains as being equal. In modern terms he had defined an integral.

In Orem’s time there was no internet, no postal service, roads were narrow and bumpy and people could not share ideas on social media. The book he wrote in Latin spread ideas very slowly until three hundred years later Galileo had the framework to describe what he was measuring.

Velocity and acceleration in the modern world

If we look at an Orem diagram for the velocity of a heavy falling body in metres per second against seconds we see at once that the area under the line (Orem’s “measure” of the velocity) has the units of metres and is the distance fallen. Orem himself, and the academics who followed him in the Monasteries and Universities of Europe in the fifteenth and sixteenth centuries did not do that. They were philosophers (thinkers) not scientists. They did not clearly understand the difference between drawing velocity against displacement and velocity against time. They did not use an Orem velocity-time diagram to describe free fall. They made no measurements. Not surprising really: they had no clocks.

Orem's idea in modern form

We have a computer. We can put numbers in a table from a video and plot (draw) a velocity-time graph on the monitor.

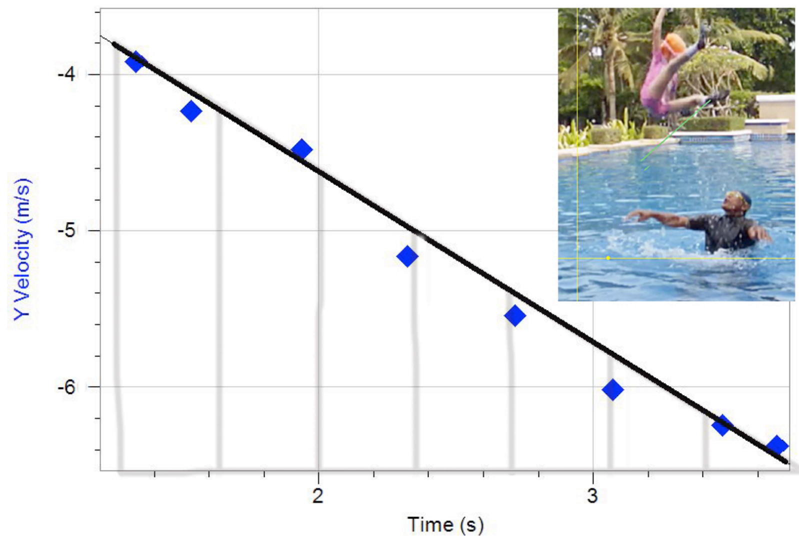

Fig 3 – an Orem diagram of uniformly deformed velocity superimposed on a velocity-time graph in Logger Pro.

We call figure 3 a *linear* velocity-time graph. This one is made for the velocity of a falling body that we find by measurement increases uniformly with time. That is the physics part. *The velocity with respect to time for a heavy body in free fall corresponds to an Orem diagram for uniformly deformed velocity*. The area of the diagram is the distance fallen. The earliest dated written account of measurements we have are by Galileo in 1604. As far as we know he was the first person to do the measurements and make the connection.

Galileo did not have a clock to measure the times for free fall. He made a groove in a board, covered it with parchment and rolled a ball down the incline. In this way he made the times longer by reducing the effect of gravity. He measured time with a bucket of water with a short pipe in the bottom. (He weighed the water that flowed in the fine jet from the pipe over the time his ball took to roll down the groove.) He thought himself lucky that his measurements corresponded to a uniformly deformed velocity with respect to time. He went on to show that the path of a projectile is a parabola with constant acceleration in the vertical direction and constant horizontal velocity. He understood the verticals could be taken as being parallel. (In modern terms: *taking the gravitational field as being constant*.) Galileo swept aside the fascination of the schoolmen of the early middle ages with diverging verticals and introduced the art of approximation to physics. He did all that with geometry not equations, but that is another story.

Further reading: https://link.springer.com/article/10.1007/s10699-012-9312-9

Kinematics in the modern classroom

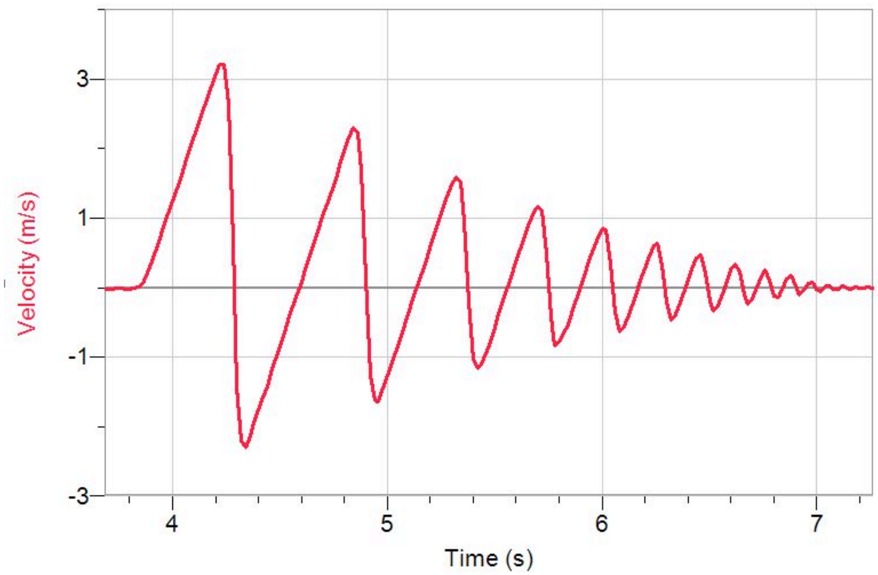

Fig 4 - the vertical velocity-time graph for a ball **dropped from 76 cm above a floor**.

What Orem might say if he could see this diagram? He would, I think, understand it as a series of uniformly deformed velocities and understand that the sum of the measure of the velocities (areas) is the distance fallen.

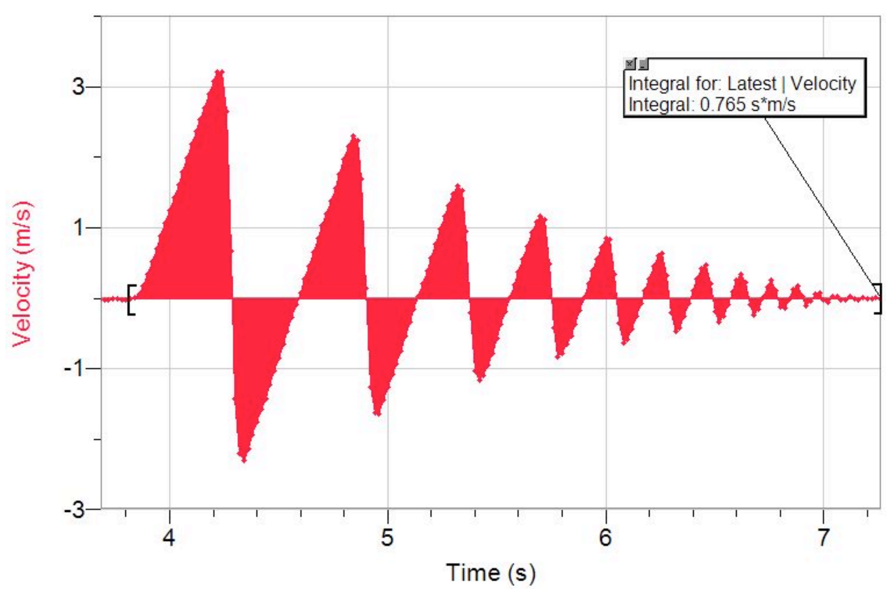

Fig 5 - the "measure of the velocity" (integral) is 76 cm. **Math not physics.**

He might have a moment of hesitation about the negative areas below the line but I think he would also understand that. What he would not know, and be surprised about, is that his uniformly deformed velocities with respect to time are what actually happens when we drop the ball. Orem in 1350 understood the math but not the physics.