TOWSON UNIVERSITY

SUPERHERO PHYSICS
AS A TEACHING TOOL IN INTRODUCTORY PHYSICS

UNIVERSITY SYSTEM of MARYLAND

LSAMP Louis Stokes Alliance for Minority Participation

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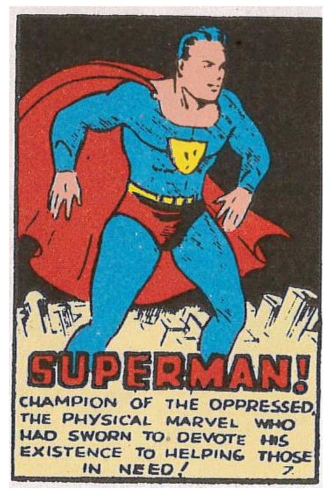


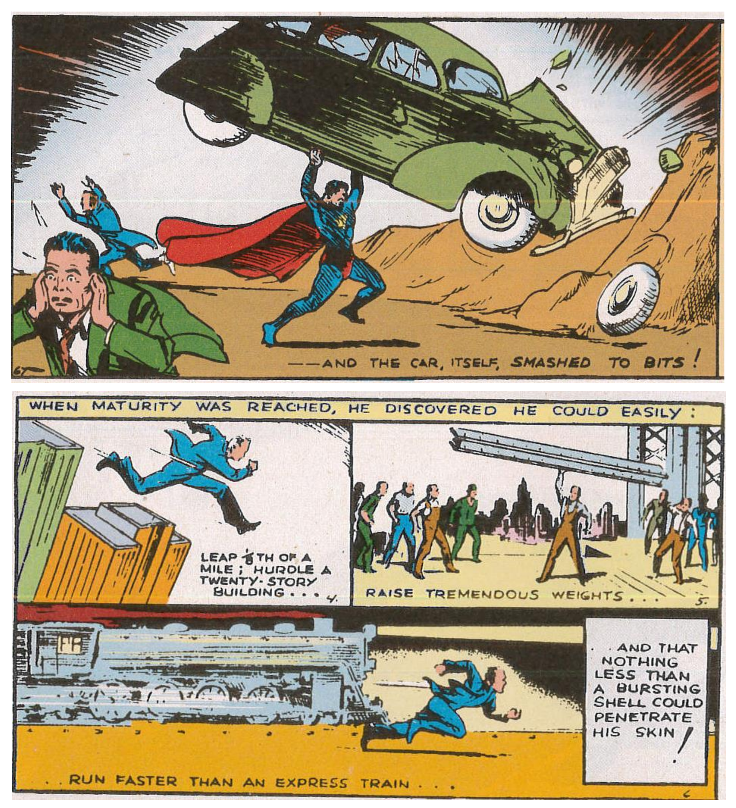


Fig. 1: Superman lifting a Chevy Master, leaping 1/8th of a mile, and running faster than a Streamliner train (*Action Comics* No. 1, June 1938)

Introduction

With a multitude of physics topics to explore, comics provide the perfect avenue for engaging young students by intertwining pop culture and science education [1]. The physics may sometimes be wrong, but it is wrong in fascinating ways that force us to confront our hidden assumptions about the way the world works.

Superman and Force

Superman was the original comic-book superhero and he needs no introduction. In his first appearance (Fig. 1) we learn that he can lift a 1938 Chevy Master (1300 kg), leap 1/8th of a mile (200 m), and outrun a 1938 Streamliner train (44 m/s). The explanation originally offered for Superman's strength by his creators, Jerry Siegel and Joe Shuster, was that Superman is essentially a scaled-up version of an insect, which can support 100 times its own weight and jump many times their own length (Fig. 2).

What's wrong with this argument? Living creatures have similar densities. Thus their weight is proportional to their volume, or $W \propto L^3$ (where L is their characteristic size). But their *strength* is only proportional to their cross-sectional *area*, $S \propto L^2$ (think of the area of a tree trunk, for example, or a person's muscles). Thus, if Superman is 200 times larger than an ant, he will be $200^2 = 40{,}000$ times stronger, but weigh $200^3 = 8$ million times as much. If an ant can lift 100 other ants, Superman will only be able to lift $100 \times 40{,}000/8{,}000{,}000 = 0.5$ people, or about 50 kg = 100 lbs (about what *you* can lift!).

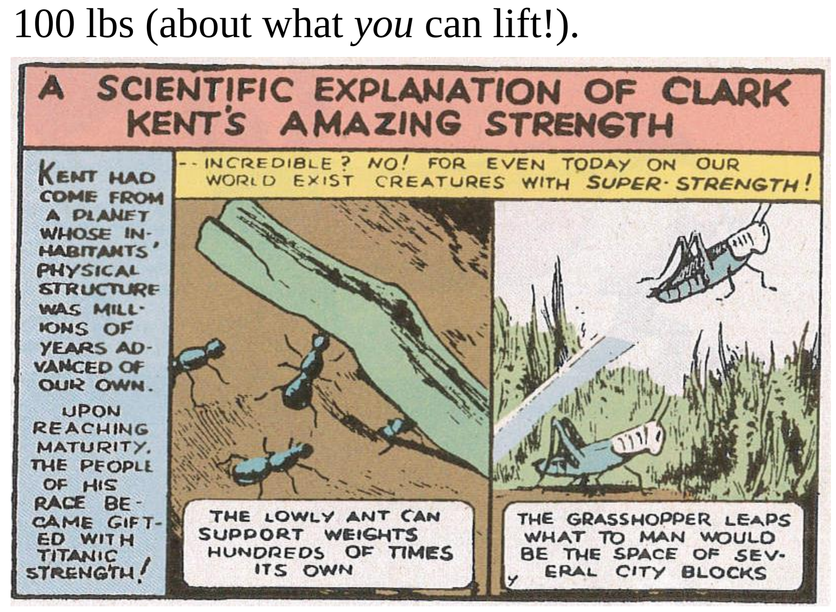


Fig. 2: the "scaling" explanation of Superman's strength (*Action Comics* No. 1, June 1938)

Fig.3: Flash deals with friction and air resistance (*Flash* #108, "The Speed of Doom" (Sept. 1959)

Creatures on any planet need to be able to lift at least half their mass; that is why an average person on Earth can lift $m = 50$ kg, exerting a force mg. But Superman can exert a force Mg where $M = 1300$ kg! Suppose he is ordinary on his home planet of Krypton. Then this feels to him like lifting $m = 50$ kg at home. I.e., $Mg = mg_K$ where g_K is the strength of gravity on Krypton. Then $g_K = (M/m)g = 260$ m/s².

Suppose Superman weighs 100 kg like us, and has a similar reaction time of 0.2 s. Then the force he exerts in accelerating to $v = 44$ m/s from rest is $F = m\Delta v/\Delta t = 22{,}000$ N. He can do this because it feels no harder than the force he exerts in holding up his own weight on Krypton! That is, $mg_K = 22{,}000$ N or $g_K = 220$ m/s², almost exactly the same as above!

Leaps are governed by the range formula $R = v^2 \sin 2\theta/g = v^2/g$ for $\theta = 45°$ (the optimal angle). This formula fits humans, who can run 400 m at $v = 9.3$ m/s and leap $R = 9.0$ m. *It also fits Superman*, who runs at 44 m/s and leaps 200 m! And it gives us a third way to find g_K from $g = v^2/R$. Assuming he can still run 44 m/s on Krypton, but only leap 9 m, we again find $g_K = 220$ m/s². Superman's physics is remarkably self-consistent!

The Flash and Speed

Flash is the fastest superhero. His physics is also surprisingly honest. In Fig. 3 we see him dealing with the problems of friction and air resistance that come along with his incredible velocity.

Fig. 4: Flash saves 12 people as a plane crashes (*Flash* #120, "Land of Golden Giants" (May 1961)

In Fig. 4, Flash saves twelve people, covering a distance of about 120 m during the 1 s that a small plane (moving at about 140 mph = 60 m/s) takes to fall 60 m to the ground. So his mean speed is 120 m/s. But he *reverses direction* each time he saves a person! Thus his acceleration during each rescue is $a = \Delta v/\Delta t = 240$ m/s /(1/12th s) = 300 g. Ordinary people cannot tolerate accelerations greater than 10 g, so Flash must have developed such a tolerance (and he will need to be careful not to subject the people he is rescuing to it).

In Fig. 5, we need to interpret Flash's thoughts with a grain of salt when he says that his speed allows him to "defy gravity". It is more that he *hardly notices* the effects of gravity. For instance, if he zooms up a wall with an initial velocity of 120 m/s, gravity will slow him by only 10 m/s after 1 s, or 120 m of travel, and 20 m/s after 240 m. He still reaches the top. How about Flash's explanation of his ability to skip from cloud to cloud? We leave this as an exercise for the reader.

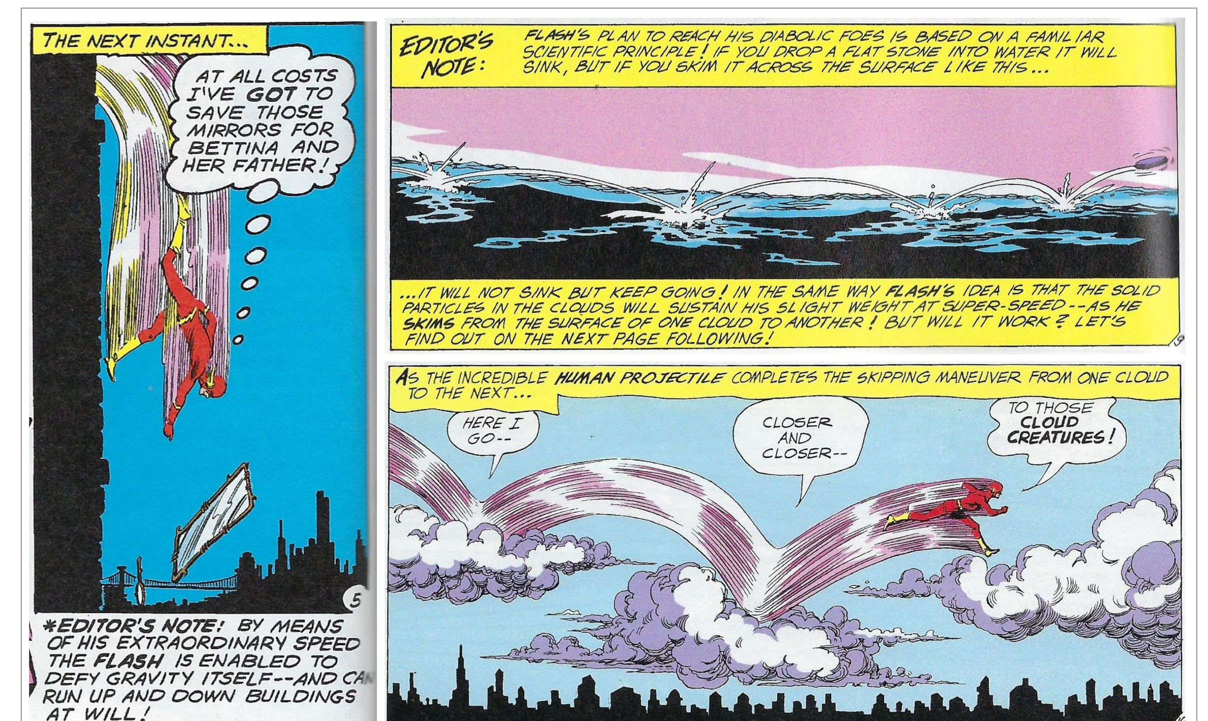
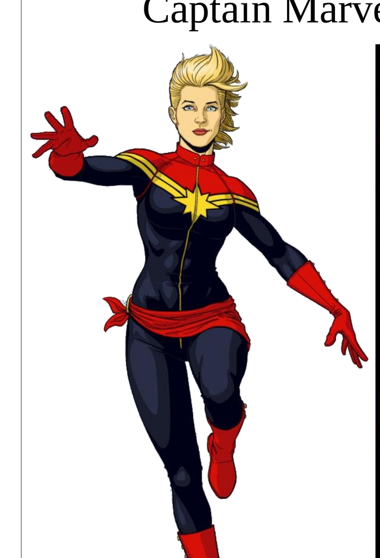


Fig. 5: Questionable physics: does Flash's speed really allow him to defy gravity (*Flash* #119, "The Mirror-Master's Magic Bullet," March 1961) or skip from cloud to cloud (*Flash* #111, "Invasion of the Cloud Creatures," Feb-March 1960)?

Captain Marvel and Energy

Captain Marvel has only exploded into popularity within the last decade, but this superhero has also had a long history in the comic-book world. Introduced as Carol Danvers in 1968, her unique ability to absorb and radiate energy has made her a standout character in recent years. Her fascinating powers (summarized in Fig. 6) can be utilized to introduce students to the concept of energy.



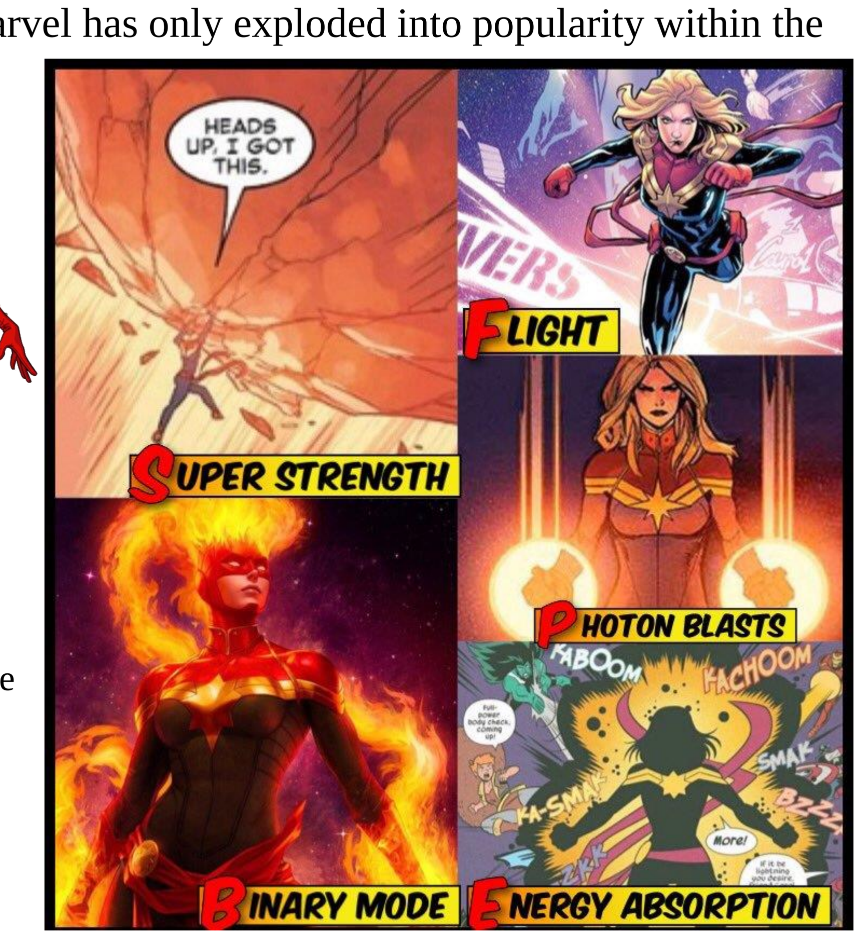


Fig. 6: Carol Danvers as the new Captain Marvel (above), with some of her fantastic physics powers (right).

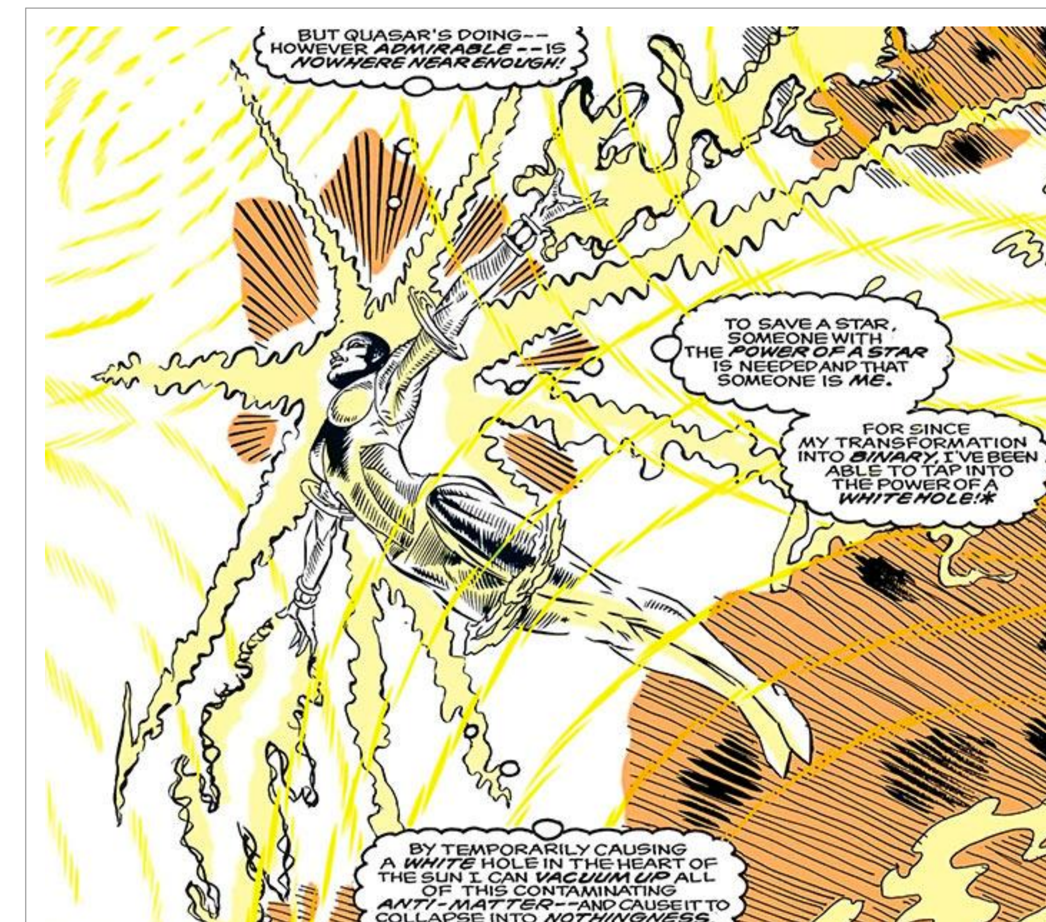


Fig. 7: Captain Marvel is able to tap into the energy of *white holes*, hypothetical counterparts of black holes from which *everything* can escape, and into which *nothing* can fall. Such objects would certainly produce a fantastic amount of energy, but harnessing this energy over large distances would present numerous practical difficulties.

For example, in Fig. 6 (top left) Captain Marvel stops a rocky asteroid headed for Earth. Using a compass, we can find the radius of the asteroid. Using Carol Danvers' height (5'11" = 1.8 m) as a scale, we find that $r = 7$ m. Assuming a typical rock density (2300 kg/m³) we then find the asteroid's mass to be 4×10^6 kg. To stop this rock (initially moving at a typical interplanetary speed of $v = 40$ km/s), Captain Marvel must do work equal to its change in kinetic energy, $\frac{1}{2}mv^2 = 3 \times 10^{15}$J.

Can she come up with that much energy? Yes! In Fig. 7, seeking energy for a different purpose, Captain Marvel converts the Sun into a white hole. As a rough estimate this would give her an energy of $E = M_\odot c^2 = 2 \times 10^{47}$ J. It is not clear how she would harness this energy, but to put it in perspective we note that the energy used by the *entire planet Earth* in a year is 110,000 TWh = 4×10^{19} J.

The above examples are only the smallest sliver of what is possible with superheroes, not only as entertainment, but as teaching tools in introductory physics. For more, we direct readers to Ref. [1].

Acknowledgments

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References

[1] J. Kakalios, The Physics of Superheroes (Avery: 2006)