Why Cats Land on Their Feet
And 76 Other Physical Paradoxes and Puzzles

by Mark Levi

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Reviewed by Andy Ruina on August 1, 2012

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This preprint includes, on pages 3-5, detailed comments not in the printed version.

This is an informal book of puzzles, solutions, jokes and personal anecdotes. It is, roughly, a condensed version of the mechanics portions of Jearl Walker's *Flying Circus of Physics (with answers)*. Levi shares Walker's pleasure in asking 'why?. But where Walker tends to look at interesting phenomena and give physics-based answers, Levi is more focussed on puzzles and paradoxes associated with physics reasoning, with an emphasis on mechanics reasoning. Levi's thinking often seems like that found in the first several chapters of the Feynman lectures. If you like Walkers book and Feynman's intuitive reasoning, I guess you will like Levi also.

Most of Levi's explanations are at a level that most mechanically inclined people, even if not mechanically educated, could at least partially understand. But they are up a level from what typical good freshman physics students could give on their own. And most people with good mechanics educations will have wrong initial thoughts about some of the puzzles. I did. And that's the fun.

Although Levi is a math professor who can write papers like 'Quasiperiodic motions in superquadratic timeperiodic potentials', in this book he tends away from formalism. Instead, he uses physical intuition, and almost no math, to reason things out. As Levi explains in the preface, the book is an advertisement for such non-formal understanding. Levi thinks of the logics describing the world as melodies and the mathematics as the notes. So this book of explanations with little math is like a tape of tunes without score sheets. But it is not a low-level math-phobic treatment of physics; the math is not there, the careful (if informally presented) reasoning is.

Here's one of Levi's several odd contraptions with odd behaviors. The surface of the water in a pot you spin on your old 45 rpm turntable will have a parabolic shape. That's cute if you don't know it yet, but that is not the puzzle. Put a cork on the water slope and watch it travel in circles with the water underneath it. But it doesn't. The cork will (and this should be surprising) spiral towards the center. Why? Because, explains Levi, the center of mass of the lighter-than-water cork would go in a circular orbit with smaller radius than the center of mass of the water that it displaced. So the pressure from the water, just right to balance the centripetal acceleration of the water displaced by the cork, is more than enough to balance the centripetal acceleration of the cork, "this imbalance pushes the cork toward the axis".

The puzzles range in their academic and physical familiarity. Some, like the falling cat from the title, are classics known to all nerds. Some, like how ship gyros find North, are well known (if you are in the gyro business) but are not part of our modern shared consciousness. And some, like why gravity imparts less and less velocity per unit distance as an object falls, are just translations of well-known math into words. Some of the puzzles, like the one about the force needed to push a container of water that has a helium balloon inside, in the absence of gravity, are thought experiments, not achievable with a home budget. Some, like the floating cork described above, are not familiar, but still realizable with some effort. And some, like how to pump a swing, are from common experience.

With these puzzles Levi promotes his kind of not-quite-mathematical reasoning. He doesn't argue as if he was trying to win a Federal case against the doubters of the often counter-intuitive phenomena. he rarely buttresses his reasoning with rigorous math, or even with precise words. Rather, he presents his questions, offers his intuitive answers and goes on to the next puzzle. Unless you are at the right the right level of trust or understanding you may have initial doubts. But I found that with some reflection I generally came around to accepting his view.

One kind of target reader already likes puzzles, mechanics and intuitive explanations. Such a person already knows many puzzles like the ones in this book. [Full disclosure, I am such a person, and I have talked through many of these puzzles with Levi over the past 15 years.] But even the puzzles one already knows well, Levi may explain with a helpful twist. For example, I know the falling cat problem from the book title well. Ive even given lectures on it. Nonetheless, Levi's drawing uses a new-to-me extra-extreme bend in the cat's spine that simplifies the mental cartoon about how a cat can rotate with zero angular momentum.

Those who don't have a taste for math, but who find random odd phenomena interesting and like to read texts they can trust, may also enjoy this book. Although they might read with some detachment, without intent of reproducing the reasoning on their own, they can nonetheless learn some cute features of how things can move, and how those motions can be explained. The light 25 page introduction to mechanics in the appendix may help fill some gaps.

For people really trying to learn how things work, things they don't already understand pretty well, I do wonder if some of the treatments are a bit short or terse. Whole papers have been written about a few of the things Levi treats in about two short pages each. With Levi's brief, light breezy descriptions I guess that some people will have trouble fully appreciating some of the puzzles. For example, such a person might think about the paraboloid of water above, 'Of course the cork falls to the bottom of a slippery bowl'. And if, like that, they can't see the puzzle in the puzzle, they might also have trouble learning from Levis explanations.

If you are predisposed to trust math and math alone, you may not like Levi's informal reasoning. But you are also then in the crowd he would like to woo. Many of his examples are based on trustworthy reasoning that takes 100 times less effort than would a detailed mathematical calculation. The perfect reader of this book already knows and likes mechanics and shares Levi's intuitive and curious style. But others, say those who know less mechanics or don't naturally take to intuitive reasoning, also have various fun bits they can learn here.

For those who buy the book and want to know where I was confused or found room for improvement, I have comments on about 35 of the puzzles at
http://ruina.tam.cornell.edu/research/topics/miscellaneous/LeviCatreveiw.pdf
(which includes the text below)

Detailed comments

The comments below are for those who read the book. They show where I was confused or found room for improvement.

- pg 15 *Speeding Up Causes a Slowdown.* In the usual change-of-orbit trajectories the ship does initially speed up. The slowing Levi describes comes later, followed by a bit more speeding at the end. The net change is, as stated, a slowing.
- pg 20 *A culinary application of Taylor-Proudman's theorem.* Is the mixing caused by the velocity differential between the stationary colored jello and the moving jello? I could not understand the experimental setup, the observation, or it's explanation.
- pg 24 *Boat in a rotating pool.* Moving out is only possible if the boat is heavy enough, or tight-fitting enough, so that the center of mass (COM) of the person-boat system can be lower than the COM of the displaced fluid. Not easy to achieve for a wood boat holding a person whose density is close to that of water.
- pg 35 *An underwater balloon.* Actually, the scale reading would initially *rise* as initially and correctly (but supposedly incorrectly) reasoned. It is not until the elastodynamic effects (wave propagation in string, balloon and water) have settled down that the balloon floats, the water falls, and the scale reading drops, as the text claims.
- pg 36 *Consider a helicopter ...* or a dolphin swimming with tail fins in the water and body above the water.
- pg 40 *What force is required ...* Some ambiguities in the boundary conditions. For example if the tube narrows and then widens the force would be zero. Also, for the sucking and blowing straw, what if there is liquid inside the mouth?
- pg 46 *Figure 5.8a* doesn't clearly-enough indicate that the nozzle orientation has a radial component. Also, this puzzle is so close to the Feynman sprinkler puzzle it is funny not to mention that one.
- pg 48 *A liquid "whip".* There is a tighter analogy between this example and the energy-conserving version of the chain described in the reference to the puzzle on page 150 than there is with a whip. Why mention the speed of sound?
- pg 55 *Flow in the pipe.* Odd to not mention Einstein's essay on circulation in curving rivers.
- pg 57 *How do Swings work?* Odd not to refer to the gymnast effect discussed on page 60 which is needed to start a swing from rest.
- pg 63 *Controlling a Car on Ice.* This handbrake-turn was known by stunt drivers long ago, and is called a Policeman's U, a bootleg, a smuggler's turn or a powerslide. As a puzzle I learned it from Tom Kane in about 1984.
- pg 64 *How Does a Biker Turn?* The Wright brothers, famous bicycle manufacturers from the turn of the 20th century, were pre-occupied with this counter-steering.
- pg 66 *Can One Gain Speed on a Bike by Body Motion Only?* Also possible with just steering, using the caster of the front wheel. This is used in the now-popular infant toy called a Wiggle-Racer.
- pg 81 *High Pressure and Good Weather.* I couldn't follow the sheep-dog effect at all.
- pg 83 *What causes the trade winds?* As written it seems to say there is a force of falling to the South. So the explanation order seems partially backwards. Rather, rising hot air at the equator has to go somewhere so some goes North and some South. The High warm Northward air eventually cools and sinks and then goes South to fill the void. Then the Coriolis stuff. The thing about the wavelengths of the radiation in and out seems out of place especially given that the winds, the topic at hand, are such a small part of the total energy budget.
- pg 91 *Antigravity Molasses.* The lack of an explanation is disappointing. More details on building the experiment would be helpful.
- pg 96 *A Rocket Problem.* For $t > 1$ the backwards motion *is* a sensible solution. If the initial velocity is less than zero the math describes the motion as the rocket grinds to a slow stop.

pg 98 *Water in a Pipe.* The answer depends on boundary conditions that are not described, as shown (implicitly) in the slithering rope example on 100-103: if there is the right suction at the entrance and exit there is no force at the corner.

pg 100 *Slithering ropes.* Credit to Routh, E. J., "Dynamics of a System of Rigid Bodies, Part 2", MacMillan and Co., 1884, London, 4th edition, pgs 299-300.

pg 105 *How Does the Spinning Top Defy Gravity?* The centripetal acceleration of particles explanation of gyroscopes is in Feynman's lectures (called, equivalently, a Coriolis acceleration by Feynman).

pg 106 *A strange force.* In the figure the label A is missing from the top of the top.

pg 107 *Energy considerations.* Not convincing, to me. Depends on all the energy being in the spin, which it need not be.

pg 113 *Staying on a Slippery Dome.* The hard part is figuring out, when there is initial falling, say, to the East, where from comes the linear momentum that is in the Northwards precession? Answer: this comes from the forces F and F' in Fig. 9.7 being *not* parallel (they are radial). But in the drawing they look parallel.

pg 114 *Finding North with a Gyroscope.* Figure 9.8 is drawn as seen from the South (rather than North) pole.

pg 122 *Molecular Ping-Pong.* I think the increase in kinetic energy due to colliding with a moving wall is in the Feynman lectures (and probably many other places).

pg 123 *A bike Pump as a Heat Pump . . . Efficiency.* The phrase "uses less energy than burning fuel" needs qualification. Turning fuel into work or electricity involves a loss of, typically 50% - 75%. So the heat pump needs to be 200% - 400% efficient to come out as a gain. And this only happens when the temperature differential is relatively small.

pg 125 *Freezing things with a Bike Tire.* This one is, I think, simply wrong. The cooling of bicycle tire air is from the imperfect-gas Joule-Thompson effect and cannot be calculated using, as Levi does use, the formulas for reversible adiabatic expansion of a perfect gas. For a bleeding valve, the neglected-by-Levy dissipation at the valve cannot be neglected because the expansion work is turned to heat there. For a perfect gas internal energy u is a function of temperature T alone: $u = u(T)$. And with no work done by the expanding fluid, and no heat flowing in or out, this is constant energy expansion. So, if air was a perfect gas (and if atmospheric pressure is negligible compared to tire pressure), there would be *no* cooling. To cool a perfect gas by expansion the molecules have to do work on the environment by, say, bouncing off of a receding piston or turbine blade.

pg 128 *Perpetual Motion by Capillarity.* If one draws a free body diagram of the fluid plus piston then the forces used by Levi to debunk the invention drop out. So the actual explanation is different. One needs to find external forces on that system to counter the driving capillary forces. I guess these are some mixture of friction and/or capillary forces where the water contact with the walls ends.

pg 136 *Sailing Straight into the Wind.* The pictured toy is shown in Scientific American, December 1975, pages 124-5.

pg 139 *Soaring without Updrafts.* Not just in principle, albatrosses do it. (e.g., P Lissaman - Technical Soaring, 2012)

pg 141 *Danger of the Horizontal Shear Wind.* Two things: 1) wind shear is a real problem for powered planes, not just gliders, and 2) need to mention the vertical separation of parachutist from the parachute.

pg 150 *It's alive!* The anti-intuitive nature of this puzzle is enhanced if the spring AB is so tight that ropes 1 and 2 are initially just slightly slack.

pg 153 *A Man in a Boat with Drag.* Here is a slightly shorter derivation. Impulse= Δmomentum for the system $\Rightarrow \int_0^\infty F dt = (m+M)\Delta\dot{C}$. Replacing F with $-k\dot{b}$ (the friction law), and $\Delta\dot{C}$ with 0 (the system starts and stops at rest) $\Rightarrow \int_0^\infty \dot{b} dt = \Delta b = 0$.

pg 155 *A "Phantom" Boat: No Wake and No Drag.* A 3D drawing or description would help. The idea is that all contacts that the boat has with the water have velocity boundary conditions where the normal component is that of the stationary water with respect to the boat. Thus, with frictionless water, the moving boat is invisible to the water.

pg 176 *Conservation of the angular momentum.* This derivation, although popular, is problematic. It depends on all internal forces coming in cancelling central pairs. This thus rests extremely accurate (about, one part in 10^8) macroscopic mechanics on an inaccurate atomic model of matter. I think most people who think hard on this feel it is be better to take angular momentum balance as a postulate or assume that, by some unknown atomic and subatomic physics, the internal forces and torques cancel.

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