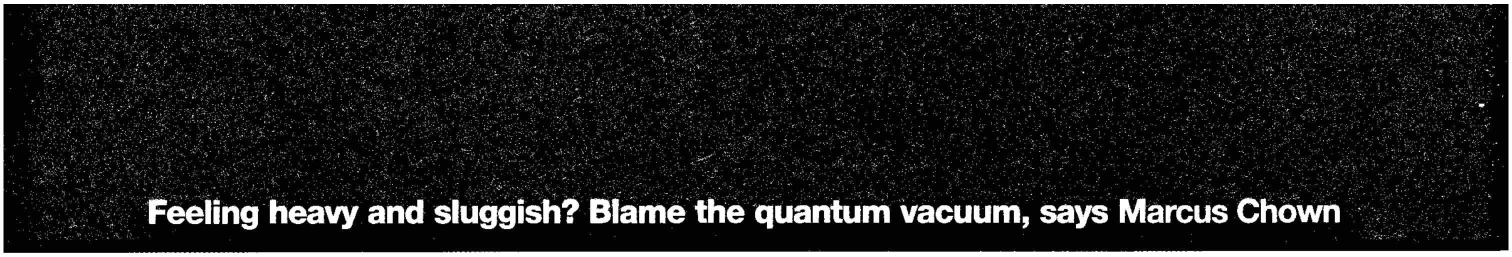

Feeling heavy and sluggish? Blame the quantum vacuum, says Marcus Chown

MASS MEDIUM

WHAT is this thing called mass? Pondering this apparently simple question, two scientists have come up with a radical theory that could explain the nature of inertia, abolish gravity and, just possibly, lead to bizarre new forms of spacecraft propulsion.

Faced with the same question, you might answer that mass is what makes a loaded shopping trolley hard to get moving—its inertia. Or, perhaps, that mass is what makes a bag of sugar or a grand piano weigh something. Either way, the origin of mass is one of nature's deepest mysteries.

Some particle physicists claim that a hypothetical particle called the Higgs boson gives mass to subatomic particles such as electrons. Late last year, hints that the Higgs really exists were found at CERN, the European centre for particle physics near Geneva. So, does the Higgs explain weight and inertia? The answer is probably no.

Wait a minute. How can these physicists claim they have discovered the origin of mass when their proposed mechanism fails to explain the very things that make it what it is? Well, as Bill Clinton might say, it all depends on what you mean by mass.

When these particle physicists speak of mass, they are not thinking in terms of inertia or weight. Matter is a concentrated form of energy. It can be changed into other forms of energy and other forms of energy can be changed into matter—an equivalence embodied in Einstein's famous equation $E = mc^2$. So in this sense, the mass of a subatomic particle is a measure of the amount of energy needed to make it. The Higgs can account for that, at least partly (see "Mass delusion", p 25).

"But the Higgs mechanism does not explain why mass, or its energy equivalent, resists motion or reacts to gravity," says Bernard Haisch of the California Institute for Physics and Astrophysics in Palo Alto. He believes instead that inertia and gravity are manifestations of far more familiar effects. When you lift that sack of

Illustration: Richard May

'This might explain why gravity is so weak. One mass does not pull directly on another mass, but only through the intermediary of the vacuum'

potatoes or shove your shopping trolley, the forces you feel might be plain old electricity and magnetism.

If the forces are familiar, their origin is anything but. For in Haisch's view, they come out of the quantum vacuum. What we think of as a vacuum is, according to quantum theory, a sea of force fields. The best understood of all these fields is the electromagnetic field, and it affects us constantly—our bodies are held together by electromagnetic forces, and light is an oscillation in the electromagnetic field.

That these fields pop up in the vacuum is reflected by Heisenberg's uncertainty principle, which states that the shorter the length of time over which an energy measurement is made, the less precise the result will be. So although the energy of the electromagnetic field in the vacuum averages to zero over long periods of time, it fluctuates wildly on very short timescales. Rather than being empty, the vacuum is a choppy sea of randomly fluctuating electromagnetic waves. We don't see or feel them because they pop in and out of existence incredibly quickly, appearing only for a split second. These fleeting apparitions are called virtual photons.

But sometimes, virtual becomes real. Stephen Hawking worked out that the powerful gravity of a black hole distorts this quantum sea so much that when a virtual photon appears, it can break free and escape into space, becoming real and visible just like an ordinary photon. And a fundamental principle of Einstein's theory of general relativity is that gravity is indistinguishable from acceleration. So if gravity can release photons from the vacuum, why shouldn't acceleration do the same? In the mid-1970s, Paul Davies at the University of Newcastle upon Tyne and Bill Unruh at the University of British Columbia in Vancouver realised that an observer accelerated through the quantum vacuum should be bathed in electromagnetic radiation. The quantum vacuum becomes a real and detectable thing.

This idea hit Haisch in February 1991, when Alfonso Rueda of California State University gave a talk about the Davies-Unruh effect at Lockheed Martin's Solar and Astrophysics Laboratory in Palo Alto. If an accelerated body sees radiation coming at it from the front, Haisch thought, that radiation might apply a retarding force. "I'm an astrophysicist," he says. "So I am used to the idea that radiation—for instance, sunlight—can exert a pressure on bodies such as comet particles."

Rueda said he would do some calculations. Some months later, he left a message on Haisch's answering machine in the middle of the night. When Haisch played it back the next morning he heard an excited Rueda saying, "I think I can derive Newton's second law."

According to Rueda, photons boosted out of the quantum vacuum by an object's acceleration would bounce off electric charges in the object. The result is a retarding force which is proportional to the acceleration, as in Newton's second law, which defines inertial mass as the ratio of the force acting on an object to the acceleration produced. Haisch and Rueda, along with their colleague Harold Puthoff of the Institute for Advanced Studies in Austin, Texas, published their initial work in February 1994 (*Physical Review A*, vol 49, p 678).

This electromagnetic drag certainly sounds like inertia. But do the calculations agree with the known inertial masses of subatomic particles? Why are quarks heavier than electrons, even though they have less charge? And why are the particles called muons and taus heavier than electrons, even though they appear to be identical in other ways? It might be because they are doing a different kind of dance.

In deriving his result, Rueda adapted an old idea proposed by quantum pioneers Louis-Victor de Broglie and Erwin Schrödinger. When low-energy photons bounce off electrons, they are scattered as if the electron were a ball of charge with a finite size. But in very high-energy interactions, the electrons behave more as if they are point-like. So de Broglie and Schrödinger proposed that an electron is actually a point-like charge which jitters about randomly within a certain volume. This can account for both kinds of behaviour: at high energies, the interaction is fast and the electron appears frozen in place; at low energies, it is slow, and the electron has time to jiggle about so much that it appears to be a fuzzy sphere.

Haisch and Rueda believe that de Broglie and Schrödinger's idea was on the right lines. The electron's jitter could be caused by virtual photons in the quantum vacuum, just like the Brownian motion of a dust particle bombarded by molecules in the air. "Random battering by the jittery vacuum smears out the electron," says Haisch.

This is important because Haisch and Rueda suspect that their inertia-producing mechanism occurs at a resonant frequency. Photons in the quantum vacuum with the same frequency as the jitter are much more likely to bounce off a particle, so they dominate its inertia.

They speculate that muons and taus may

be some kind of excited state of the electron, with a correspondingly higher resonance frequency. That would probably mean a greater mass, as there are more high-frequency vacuum photons to bounce off. Quarks might also be resonating in a different way from electrons. "If we knew what caused the resonance we would probably be able to explain the ratio of the various quarks' rest masses to the electron rest mass," says Haisch. The cause of such excitations might lie in string theory, which treats particles as tiny vibrating strings, but this is only conjecture.

If inertial mass is an electromagnetic effect, why does the neutrino appear to have some mass, even though it doesn't feel electromagnetic forces? This might be easier to explain. The electromagnetic field is not the only field in the vacuum. There are two other force fields: the weak nuclear force and the strong nuclear force. Both could make contributions to mass in a similar way to the electromagnetic field.

Neutrinos only feel the weak force, which could explain their small mass. Quarks feel the strong nuclear force, and that could affect their mass. It is even possible that strong-force fluctuations in the vacuum dominate the masses of quarks and gluons. As these contributions are much harder to work out than the electromagnetic ones, no one has attempted them yet.

Vacuum-packed

So much for inertia. But what about the force holding you to the floor? Can the vacuum account for gravitational mass too? The idea of linking gravity with the quantum vacuum was suggested by Russian physicist Andrei Sakharov in 1968 and has been developed recently by Puthoff. Haisch and Rueda's latest project is to connect this idea with their work on inertia.

It's still highly speculative, but they think they can explain away gravity as an effect of electromagnetic forces. Oscillating charges in a chunk of matter affect the charged virtual particles in the vacuum. This polarised vacuum then exerts a force on the charges in another chunk of matter. In this rather tortuous manner the two chunks of matter attract each other. "This might explain why gravity is so weak," says Haisch. "One mass does not pull directly on another mass but only through the intermediary of the vacuum."

Einstein's theory of general relativity already explains gravity beautifully in terms of the warping of space-time by matter, so this "geometrical" description ought to be compatible with the quantum-vacuum picture. Haisch points out that the curvature of space can only be inferred from the bending of the paths of light rays. But the polarised vacuum would bend light paths, just as a piece of glass does when light enters or leaves it. "The warpage of space might be equivalent to a variation in the refractive index of the vacuum," Haisch conjectures. "In this way, all the mathematics of general relativity could stay, intact, since space-time would look as if it were warped." And all the strange predictions of general relativity, such as black holes and gravitational waves, would be manifestations of this polarised vacuum.

If they can get their idea to work, Haisch and Rueda will have a theory of quantum gravity—the long-sought marriage of Einstein's general relativity with quantum mechanics. It would finally allow physicists to understand the first moments after the big bang, and the crushing singularity at the core of a black hole.

That just leaves rest mass, the kind of mass that's equivalent to energy. According to Haisch, the Higgs might not be needed to explain rest mass at all. The inherent energy in a particle may be a result of its jittering motion, the buffeting caused by virtual particles in the vacuum. "A massless particle may pick up energy from it, hence acquiring what we think of as rest mass," he says. If this were the case, all three facets of mass would be different aspects of the battering of the quantum vacuum. "It would be a tidy package."

It may be that there is no explanation for inertial and gravitational mass. They may just come hand in hand with rest mass. This is what many particle physicists believe. "Some people think Haisch and Rueda are on the right track, others think they are on a wild goose chase," says Paul Wesson, an astrophysicist at the University of Waterloo in Ontario, Canada.

But if gravitational and inertial mass do emerge from the vacuum, perhaps we could take control of them. It might be possible to cancel mass, creating an inertia-less drive that could accelerate a spaceship to nearly the speed of light in the blink of an eye. To do this we would have to exclude quantum fluctuations from a region where there is matter—blow a bubble in the vacuum. Haisch doesn't know if that is possible. "Nature does not abhor a vacuum," he says. "However, it may abhor a vacuum in the vacuum." □

Further reading: www.calphysics.org/inertia.html

Mass delusion

Most theories that attempt to unify the forces of nature, showing them to be facets of a single "superforce", treat all subatomic particles as having zero rest mass. So they need an extra ingredient—the Higgs boson.

The idea is that space is filled with Higgs bosons, and every subatomic particle gathers a crowd of them around it. According to Frank Wilczek of the Massachusetts Institute of Technology, this explains how the rest masses of subatomic particles come about. There is some energy in this gathering of Higgs particles, corresponding to the energy in $E = mc^2$.

"But it doesn't explain the actual values of their masses—why, for instance, the top quark has a million times the rest mass of an electron," he says. The value of the mass depends on how well the Higgs sticks to the particle, and no one knows what governs this.

And it gets worse. The Higgs mechanism explains hardly any of the rest mass of ordinary matter. The stuff of everyday life consists mostly of protons and neutrons, which are in turn made of particles called "up" and "down" quarks, held together by gluons. But gluons have no rest mass, and these two quarks have very little—not enough to add up to the masses of protons and neutrons.

Instead, most of the mass of ordinary matter comes from the "colour field", the force that binds quarks and gluons together. Even when a proton isn't moving, all this energy is sitting there inside it. So the Higgs mechanism explains only a tiny part of the rest mass of ordinary matter.

"Whether you call this an explanation of mass is a matter of taste, I guess," says Wilczek. "I would be inclined to say no, since it doesn't simplify the description of mass, nor suggest testable new properties of mass."