May the Force Be With You

Empty space is full of invisible force fields, and we can detect electromagnetic fields from the farthest reaches of the universe. So couldn't our thoughts generate electromagnetic fields that might be sensed by other people? Here's the problem.

LAWRENCE M. KRAUSS

You gotta love this place. Every day is like Halloween!

—Fox Mulder

Early in the first film of the *Star Wars* trilogy, Obi Wan Kenobi urges Luke Skywalker to "feel the Force!" To no one's surprise, Luke does, eventually, and it is very very good to him. It was also very, very good to George Lucas. A billion dollars and twenty years later, the Force is still with us.

Tell me that you have not, at some time in your life, looked up at the night sky and shuddered at the vast loneliness of our existence. Or, sitting alone in a darkening room, perhaps in a remote cabin in the woods, have you never, as a barely perceptible chill breeze brushed your skin, had an idea that there might be some "thing" in the room with you, which you cannot see? What are the things that go bump in the night?

Dark side or not, there's something particularly cozy about an invisible Force that ties the universe together and gives it meaning, coherence, legitimacy. Pondering the existence of aliens may be how we ease our innate human loneliness nowadays, but pondering the existence of invisible forces is nothing new. Such musings are, after all, at the heart of most of the world's religions, whose annual gross stretches back for millennia and makes Lucas's look like chicken feed.

In fact, invisible forces are not merely the stuff of revelation: they *are* everywhere! Turn on your radio, and suddenly there is music, borne by invisible radio waves. Leap into the air, and the force of gravity pulls you back to Earth. Pluck a couple of magnets off the refrigerator and feel them push away from each other. As a matter of fact, there is almost no such thing as a visible force! I say "almost" because, of course, if a piano falls on your head, the source of the force you feel (before you feel nothing anymore) is eminently visible! Or is it? What is it about the piano that makes it "material"? Why does it crush your skull?

This might seem like a silly question; after all, what could be more solid than wood, ivory, metal, all the things from which a piano is fabricated? Well, a piano, at the fundamental level, is made of billions and billions of atoms. You can therefore reasonably assume that the particles in the atoms in the piano smack up against the atoms in your head and the multiple collisions are what cause one of these atomic aggregates to spatter.

Ah, nothing could be further from the truth. No particle in any atom in the piano—no proton, neutron, or even electron—ever gets close, on an atomic scale, to any particle in any atom in your skull. Most of what we like to think of as "matter" is actually empty space. The region in which electrons orbit an atomic nucleus is more than 10,000 times as large as the nucleus itself. It's the invisible electric forces emanating from the charged particles in the atoms in the piano that repel the charged particles in the atoms in your head and do such a good job of making both your head and the piano seem solid.

Physicist Richard Feynman used this idea to relate the strength of the electric force to the gravitational force. I will repeat his argument here, changing it slightly so we can continue to speak in terms of your head and the piano. But instead of dropping a piano on your head, let's drop your head on a piano from, say, 100 floors up. Let's assume you are at the top of the Empire State Building, which I seem to remember from my youth has 102 stories. And say that you manage to climb over the high fence around the observation deck and do a swan dive toward the ground below. At the same instant, some piano movers have taken a union-required break from their chore of moving a new concert grand into the lobby of the building. The piano is still in several pieces, which are lying on mats on the sidewalk. Suddenly the movers look up, and to their horror they see you hurtling earthward. You land on the instrument's elegant, polished wooden lid, which is lying flat on the ground.

Now, says Feynman, gravity has been accelerating you for 102 stories, but you don't continue your descent toward the center of the Earth: The electrical force—in this case between the atoms in the lid (in turn supported firmly by the sidewalk) and the atoms in your head—stops you cold in a fraction of an inch! Despite its spectacularly noticeable effects, gravity is the weakest force in nature.

Even this example doesn't do justice to how weak gravity really is compared to the electric force. Here's another one: Take a single electron, which has a small electric charge associated with it. If I put another electron near it, they are repelled by the electric force between them. In empty space, where no other forces were around to balance this force, they would fly apart. Now, say I wanted to pin the second electron down by putting a large mass on top of it, so that the gravitational attraction of the large mass (plus the electron) toward the original electron would exactly balance out the electric repulsion between the two electrons. How big a mass would I need?

When I asked my wife this question, she asked how far apart the two electrons were, which is a good question. However, in this case it is irrelevant, because both the electric force and the gravitational force vary the same way with distance, so if they balance out at one distance, they will balance out at all distances. In any case, the answer is nothing short of flabbergasting. Plugging in the relative strengths of gravity and the electric force, it turns out that the mass you have to put on top of the second electron to counteract the electric repulsion is—get this!—5 billion tons. This is not only more massive then either the Empire State Building or the twin towers of the World Trade Center, or any other Manhattan skyscraper, it is more massive them all of them put together!

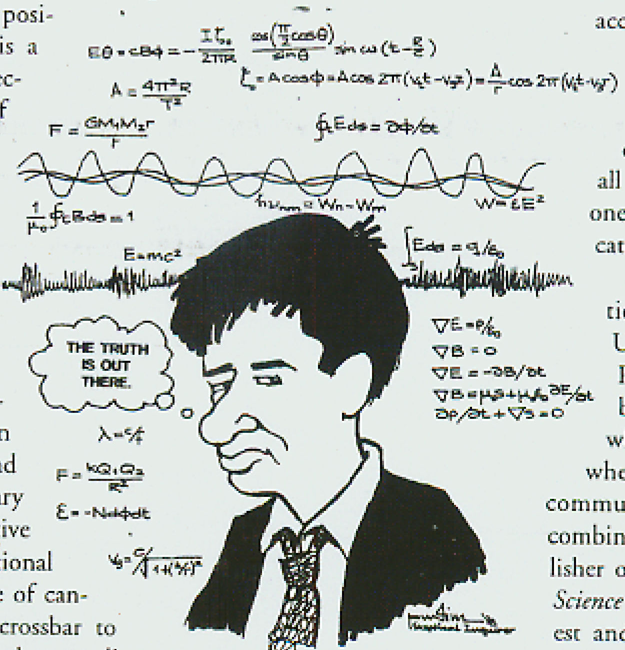
Even though I have been for some time familiar with the relative strengths of gravity and the electric force, I was surprised by this particular result after obtaining it—so much so that I had to check my calculations three times and then ask a graduate student who happened to be walking by my office to check them to make sure I hadn't done something foolish. This time, I hadn't.

Why, you may naturally ask, don't we just use small electric charges to levitate buildings or large flying saucers? The answer is that these objects, if they are at Earth's surface, are not merely attracted downward by the gravitational force of the single electron that one might hope to levitate them with, they are attracted by the whole Earth. And since Earth is massive indeed, their "weight" at Earth's surface is enormous compared to the force of electrostatic repulsion between electrons located any reasonable distance apart. On earth, all these skyscrapers are extremely heavy, but in empty space they are nearly weightless. The reason that all of these skyscrapers combined are needed to

Lawrence Krauss is Ambrose Swasey Professor of Physics, professor of astronomy, and Chairman of the Physics Department at Case Western Reserve University, Cleveland, Ohio, 44106. He is author of such popular books as The Physics of Star Trek *and* Beyond Star Trek: Physics from Alien Invasions to the End of Time *(Basic Books, Perseus 1997), from which he has extracted this article.*

balance the electric force with gravity in empty space is not that this electric repulsion is so great but that the gravitational attraction of the electron on each of these objects is so small.

Gravity is so weak that it is almost miraculous that we can detect it at all. The reason we "feel" gravity is that although the pull of each individual atom in the earth on each individual atom in my body is unbelievably small, the effect adds up, so that the attraction of *all* the atoms in the earth on each atom in my body is substantial (most noticeably in the morning, just after my alarm goes off). We don't "feel" the electromagnetic force in this way, because the negative charges in our body are exactly canceled by the positive charges in our body. This is a good thing; if it weren't so, the electric forces would explode us out of existence.



As weak as gravity is, we can still measure the gravitational attraction between human-scale objects. (The attraction between single atoms is so small that there's no hope of measuring it directly in the near future.) In fact, about 100 years after Newton's discovery of the law of gravity based on the motions of the planets around the sun, a fellow Englishman, Henry Cavendish, came up with a sensitive method to measure the gravitational attraction between objects the size of cannonballs by attaching two to a crossbar to form a kind of dumbbell balance and suspending it from a wire. He then moved a third cannonball close to one end of this contraption and measured the infinitesimal torque this produced on the wire. In this way, the fundamental strength of gravity itself—the so-called gravitational constant—was determined. Previously, one could use Newton's law to calculate the strength of the gravitational force between planets and the sun, or between Earth and the Moon, for example. However, the mass of these objects was not independently known; one could not determine how strong the gravitational force was between objects of known mass in this way. After Cavendish's experiment, not only was this measurement possible, but one could put the gravitational constant into Newton's law and in this manner *weigh* the planets and the sun. The current best measurement of the mass of the sun was calibrated using this technique.

The purpose of my discourse on gravity's weakness, however, is not to bury gravity but to praise it. There is nothing basically wrong with imagining a universe full of invisible things, some of which are beyond our control. The universe is full of invisible things, some of which *are* beyond our control! We should think about gravity whenever we ponder the Big Question that has stirred our imaginations for centuries (and inspired much of modern science fiction): What invisible things are still invisible?

At the top of the list, anyone's list, must be ESP. It's difficult to name a major work of science fiction or fantasy that does not somewhere contain an element of telepathy. Each of the *Star Trek* series, for example, has had its telepaths: Spock, Deanna Troi, her mother Lwaxana, Kes—to say nothing of a host of telepathic aliens on various planets. The aliens in *The X-Files* perform telepathic mind scans; and even the disgusting creatures in *Independence Day,* whose only purpose in life seemed to be to kill other species, used telepathy as a weapon.

How many times have you felt that you knew what someone else was thinking? Certainly, as we become accustomed to reading body language and facial expressions, we can sometimes anticipate other people's reactions, or even divine what is on their minds. Is it all that crazy to imagine that with one more step we could communicate without speech?

The term "extrasensory perception" was coined by the Duke University researcher Joseph Banks Rhine, who wrote a well-known book by this name in 1934 in which he claimed to have overwhelming evidence for telepathic communication. His popularizations, combined with the interest of the publisher of the pulp magazine *Astounding Science Fiction,* helped fuel public interest and inspired a raft of ESP-related science fiction. Rhine also coined the term "parapsychology," for the study of various kinds of alleged psychic phenomena.

Alas, the invention of these two serviceable terms was probably Rhine's greatest contribution to science, since essentially all of his ESP results that were subjected to outside scrutiny were shown to be flawed—including his first discovery, Lady Wonder, the telepathic horse. While the flawed experiments of one researcher cannot be used to dismiss a whole field, the following facts are not in dispute:

1: In the more than sixty years since Rhine created the field, there has been not a single definitive experiment broadly accepted—that is, by scientists not directly involved in similar lines of research—which unambiguously demonstrates the reality of any of the phenomena he set out to explore and promote.

2: At the same time, huge numbers of people, including a number of active workers in this field, believe that ESP exists.

I know better than to try and resolve this debate. Moreover, I have never personally tried to verify or debunk any specific set of ESP experiments. I'm skeptical, but then I try to be skeptical of everything (I don't believe there's any other way to learn about how the world really works). But I don't want to directly question here the quality of current research in this area. Rather, I want to ask a question I think is more enlightening, not to mention more fun: What would be required for ESP to exist?

I find it significant that the furor over telepathy and ESP began within a few decades of the invention of the radio by Guglielmo Marconi, and less than one decade after its first widespread usage. Once wireless communication became a reality, the idea that invisible "waves" of some sort could lead to direct nonverbal communication between people probably became a lot more plausible. Until then, the only nonverbal communication that didn't make use of some overt physical connection between source and receiver involved visible light, so that any suggestion that one might receive invisible signals was completely unprecedented. Radio waves fit the bill perfectly.

There are so many remarkable aspects of radio waves (which, like visible light, are electromagnetic waves, but of much lower frequency), that it's hard to know where to begin talking about them. First and foremost, in spite of both the curvature of the earth and the long distances involved, shortwave radio signals can be received on the other side of the planet. Moreover, though radio waves carry very little power, they can be precisely detected. The most striking illustration of this sensitivity is afforded by the marvelous Arecibo radio telescope in Puerto Rico. Built in a natural crater surrounded by tropical vegetation, the Arecibo antenna is 1,000 feet across, and viewers of the movie *Contact* will recognize it. It has detected radio waves from the surface of Venus, from rotating neutron stars thousands of light-years away, and from extragalactic objects hundreds of millions of light-years away. I toured the facility with the assistant director a while back along with my wife and daughter, and I remember trying to think of a way to convey how sensitive this beautiful device was. Based on the sensitivity data for the instrument, I worked out that it could easily detect a 25-watt lightbulb on Pluto, several billion miles away, if instead of generating visible light the bulb emitted its energy as a radio frequency accessible to the telescope's receivers.

Well, if we can detect such small sources located in the outer reaches of the solar system, why shouldn't two minds be able to communicate across a room? After all, thinking itself involves precisely the same processes as those that produce electromagnetic disturbances. Thoughts and actions are initiated by the firing of neurons in our brains, which produce electrical currents, which in turn travel to nerves and muscles elsewhere in our body. Electrical currents are precisely what generate electromagnetic waves.

On the surface, the forces of electricity and magnetism seem very different. Permanent magnets exist, but they behave quite differently than electric charges do. For example, if one cuts a magnet in half, one does not produce an isolated north pole and an isolated south pole; instead, one gets two smaller magnets, each with a north and south pole. But if I bisect an object with a positive electric charge on one side and a negative charge on the other, I will end up with one positively charged object and one negatively charged object. There is clearly some connection between electricity and magnetism, however. For example, I can create a magnet by moving charges to produce an electric current. These electromagnets are standard components in almost every electric appliance in your house.

Near the end of the nineteenth century, one of the greatest theoretical physicists of that era, the Scottish physicist James Clerk Maxwell, arrived at one of the greatest intellectual unification of ideas that has ever taken place. He demonstrated conclusively not only that electricity and magnetism were related but that they were really just different aspects of the same thing. One person's electricity is another person's magnetism, depending on the reference frame.

Besides setting the stage for relativity theory, which is based on this principle, Maxwell's theory of electromagnetism made a central prediction: Light is a wave of electricity and magnetism. The interplay between electricity and magnetism was such that whenever you jiggled an electric charge, a "wave" of electric and magnetic disturbances traveled outward at a speed that could be calculated from first principles. This speed turned out to be the same as the measured speed of light. We now understand that the frequency with which you jiggle the charge determines the measurable characteristics of the resulting wave. If you jiggle it back and forth only a million times per second, you will produce radio waves. If you jiggle it back and forth a billion times per second, you will produce microwaves. If you jiggle it back and forth a million billion times per second, you will produce visible light. And so on.

You might ask, what is it exactly that is propagating in an electromagnetic wave? What is there in the wave itself, and what will the wave do when it encounters matter? Here we have to thank another remarkable nineteenth-century British physicist, Michael Faraday. Faraday is in some ways a more romantic figure than Maxwell. Without a formal education, as a mere bookbinder's apprentice, he attended a public lecture in 1812 at the esteemed Royal Institution, in London, given by the brilliant chemist Sir Humphry Davy. Sometime later he returned to the institution with the lecture notes he had taken, bound into a handsome volume. Davy was so impressed that he took Faraday on as an assistant. The rest is history.

The particulars of this history involve a number of seminal discoveries about the connections between electricity and magnetism which set the stage for Maxwell's work. But the one I want to focus on here is one that changed forever the way physicists think about empty space. Faraday was an intuitive, seat-of-the-pants type of thinker, which is one reason I like him so much. Prior to Faraday, when physicists thought about forces, like gravity, they pictured the equations that governed these forces. Faraday provided a more intuitive, physical picture, which in some ways is far more valuable.

From the moment Newton discovered the universal law of gravity, he and others were puzzled by the question, How does the Moon know Earth is there in order to be attracted by its gravitational pull? That is, what exactly is it that communicates the force of gravity? Is that force instantaneous, or does it take time to reach the Moon?

Newton never resolved these thorny questions, and preferred to move on to other things, including becoming head of the British Mint. Some 200 years later, however, Faraday pondered the same questions, but this time in the context of the electric forces between particles. To help himself understand why the electric force behaves the way it does, he imagined that emanating from every charged particle was an electric "field." He pictured this field as a set of lines radiating outward in space from the particle in every direction. If he imagined the number of lines as proportional to the magnitude of the electric charge on the particle, Faraday could then understand why the electric force dropped off in strength with the square of the distance between charged objects. If I start out with a certain number of field lines emanating from a charge, and each one heads out in a straight line to infinity, the field lines will diverge. Therefore, the number of field lines that cross any given area at a certain distance will decrease with the square of the distance.

Now, this is a nice picture, but is it more than just a metaphor? Often physicists create pictures to give themselves a clearer understanding of how the laws of nature work, but are these pictures ever the image of the reality itself? Sometimes the answer is a surprising yes. Faraday's fields are such an example, and soon took on a life of their own. It was shortly understood that under certain conditions electric and magnetic fields could be generated simply by the presence of other electric and magnetic fields, without the presence of the electric charges that caused one to invent the fields in the first place.

When physicists nowadays think of empty space—space devoid of matter—they realize that it's not necessarily empty. We now think of the electric force, and also the gravitational force, as follows: A charged particle creates an electric field around itself, and a massive particle creates a gravitational field around itself. These fields propagate at the speed of light, and a far distant object can interact with them and be attracted or repelled. Because it takes some time for the fields to propagate, the Moon, for example, will be gravitationally attracted to where Earth was at the time the field with which the Moon is interacting was created. If Earth moves in the meantime, the Moon will nevertheless move toward the original place—that is, until the field created by the now-moved Earth propagates out to the position of the Moon. Because these fields propagate at the speed of light, we don't normally notice the delay on a human timescale. However, when cosmic distances are involved, the effects of the finite propagation speed of gravity can be dramatic. For example, the Milky Way is falling toward a huge galactic group some 50 million light-years away. In the time it has taken for the gravitational field of the huge cluster of galaxies to propagate to the region of our own galaxy, the cluster has moved from the position to which our galaxy is being attracted by perhaps 100,000 light-years, a distance comparable to the Milky Way's diameter!

Empty space is full of fields. A million years after I jiggle an electric charge here on Earth, the changing magnetic and electric fields have propagated a million light-years away, where they can cause an electric charge in an antenna attached to a radio receiver to jiggle up and down, producing a response in the receiver. The opening sequence of *Contact,* in which we pass slowly out through space, following the stream of electromagnetic waves emanating from our radio and TV broadcasts as they make their way through the universe, is a wonderful illustration of this idea.

We sense directly only a small part of all the electromagnetic waves out there. This spectrum includes waves with frequencies to which the electrons in the atoms in our eyes can respond, sending signals to our brain which we interpret as one or another color. Waves of slightly lower frequency are invisible to us, but we nevertheless feel them as heat. Waves of slightly higher frequency are invisible—to us, though not to, say, bees—and we don't feel them at all, but they damage our skin and produce dangerous but apparently appealing suntans.

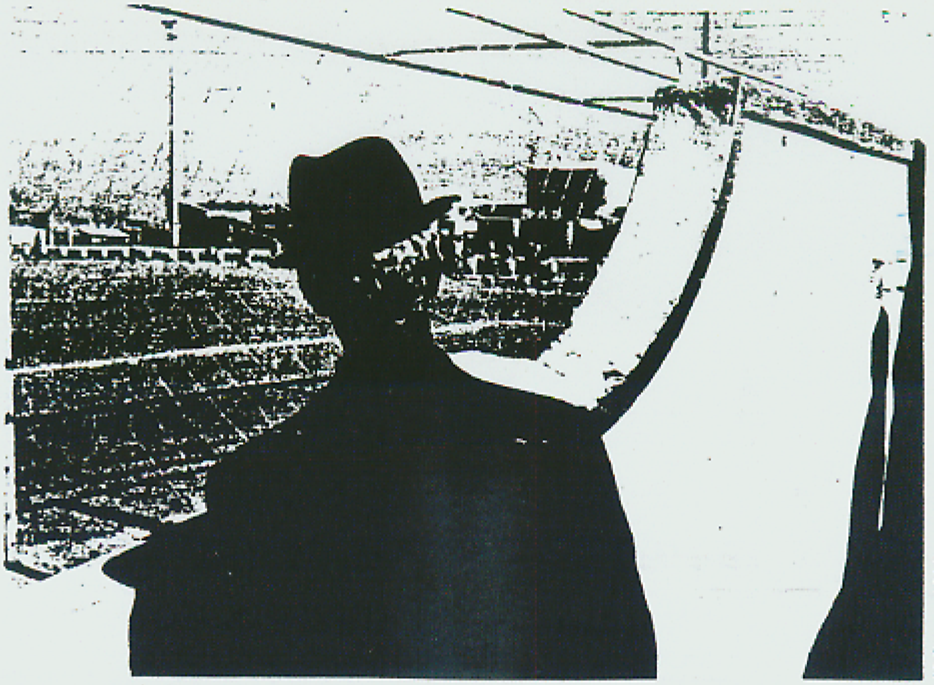
What could be more New Age than this? An invisible world full of electromagnetic fields all around us, some of which we generate by our own thought processes. How cosmic . . . ! Why couldn't our thoughts generate weak fields that might be sensed by individuals with just the right kind of antennas built into their brains?

But this is a case of too much of a good thing. Electromagnetic fields are remarkably good at propagating and producing effects. But if they produce effects, they are by definition *observable.* That's the way the world works. If I think very hard—whatever that means—and try to produce a response in your mind, that means I must induce some chemical or electric response in the neurons in your brain. But unless you think your brain behaves differently from any other sort of antenna in the universe, then the signal I send to your brain should be detectable by radios or other types of electromagnetic receivers in the vicinity.

There's no doubt that the most sensible carrier for telepathic messages would be electromagnetic waves. There's no doubt that they are directly associated with the operation of your thought processes. We have detected "brain waves" and can even measure the external electromagnetic signal they produce. But electromagnetic waves from the other end of the universe are detectable by receivers here on Earth. Why should such receivers be less efficient at receiving telepathic messages than your brain is? The fact that no one has ever detected electromagnetic waves associated with ESP is pretty damning, don't you think?

Maybe the electromagnetic waves associated with telepathy are so weak that existing detectors are insensitive to them? But they can't be too weak to generate some physical disturbance in the brain of the recipient. This would entail carrying enough energy to cause an electron to jiggle, or an atomic spin to wobble, or something. But this same something can be used as the basis of some detection apparatus or other. Existing detectors of visible light can detect, for example, individual photons. We can build X-ray detectors to see through what we cannot see through with the naked eye, infrared-sensitive cameras to spy on our neighbors in the dark. The bottom line is that there is nothing more detectable in the universe than electromagnetic waves, as hidden as they seem.

No, this is another case where Fox Mulder's maxim, "The easiest explanation is also the most implausible," holds true. If ESP is to work, there's gotta be another way—something not quite so easy. □



M Ormerod/Millennium

I know you're looking...

Does this man have eyes in the back of his head?

EVER get the feeling you're being stared at? Well, you probably are, according to research carried out by *New Scientist* readers. Biologist and author Rupert Sheldrake claims the research confirms that people can sometimes tell when they are being stared at even when they can't see the person doing the staring. However, sceptics still doubt that these results represent a mysterious sixth sense.

In 1997, *New Scientist* ran an article describing Sheldrake's attempts to investigate the notion that people somehow know when someone is watching them, even in the absence of conventional sensory information ("Are you looking at me?", 26 July 1997, p 39). Sheldrake claimed to have data backing the claim, and readers were invited to repeat his experiment in their own homes. They were told to put blindfolds on and sit down with their backs to other volunteers, who then stared at them or looked away according to a random series of numbers. Each time, the blindfolded people simply had to say whether they believed they were being stared at or not. They then sent their results to Sheldrake. Some but not all the tests were supervised.

By guessing alone, those being stared at should score a hit rate of just 50 per cent. But according to Sheldrake, analysis of results from almost 5000 trials shows that they correctly guessed when they were being stared at almost 55 per cent of the time. Although small, the difference between this and the expected score from simply guessing was statistically significant. When they were not being looked at, their success rate fell back to 52 per cent, which is not statistically different from the figure expected by chance alone.

"These results suggest that the feeling of being looked at from behind is a real phenomenon that depends on factors as yet unknown to science," says Sheldrake.

Experts in parapsychology research are intrigued by the results. But they are wary of relying on any findings obtained outside tightly controlled laboratory conditions. Chris French of Goldsmiths College, London, believes the starers could have inadvertently been providing the experimental subjects with other sensory cues as to whether or not they were being looked at. "The less well controlled a study is, the more likely this sensory leakage is to be a problem," he says.

Richard Wiseman, a psychologist at the University of Hertfordshire in Hatfield, who has also investigated the staring phenomenon, with mixed results, says the high statistical significance of the results means that you would not expect to get them as a result of chance alone. "But that doesn't imply that the staring effect must therefore be real," he says. The positive results may reflect a tendency among people who failed to obtain impressive results not to bother sending them to Sheldrake for analysis.

But Sheldrake is confident about his results. "Sceptics insist that extraordinary claims require extraordinary evidence," he says. "It's now the sceptics who are making the extraordinary claims by rejecting findings such as these." **Robert Matthews**

Feel the Force (of Physics)

Read the articles "**May the Force Be With You**" and "**I know you're looking...**" from the packet handed to you recently. Critically read, analyze, and take notes on these articles, and then address the questions listed for you below by writing your responses on a separate sheet of paper. Be sure that your answers are clearly written in complete sentences, and that they are thorough. This homework assignment is worth 10 points. DO NOT RECOPY THE ARTICLE!

"May the Force Be With You":

1. According to modern physical theories, when two objects collide with each other, does the material that (atoms) make them up actually come into physical contact? Why or why not? If not, explain what is happening on the microscopic level.

2. Perform a calculation demonstrating the relative strengths of the gravitational and electrical forces between two protons. Explain why this result seems counter-intuitive, seeing as how scientists say that it is gravity that holds the universe (on a large scale) together.

3. What are the properties of radio waves that make them very desirable as being useful for communication & detection over long distances? What is the basic mechanism that generates radio waves and other forms of electromagnetic radiation? In this physical process, what exactly determines the type of electromagnetic wave (UV-rays, infra-red, visible light, radio, etc.) that is generated?

4. Do electromagnetic and gravitational fields move at an infinite speed; that is, are their effects instantaneous? Provide an example illustrating your response. Tell why or why not early physicists (i.e., Newton, etc.) took this factor into account with their studies.

5. Why would electromagnetic waves seem the most appropriate carrier for telepathic messages? What physical & biological processes take place in our bodies that would lead to the generation of an electromagnetic wave? Describe these processes in detail.

"I know you're looking...": (Bonus Points)

6. (5 points) Think about the home ESP experiment that was conducted as a survey by Rupert Sheldrake and his colleagues. Had your family been surveyed by their study, describe in detail (pictures & floor plans might help) how you would conduct a carefully controlled home ESP test. What were the results of Sheldrake's survey? List various factors that could have affected the results of the survey & experiments. In addition to listing these factors, provide controls to offset them so that the ESP experiments are as "bulletproof" as possible.