# SHADOW MATTER

By DIETRICK E. THOMSEN

Who knows what secrets lurk in the heart of the universe? The shadow knows — shadow matter, that is. Shadow matter is yet another species of matter that theoretical physicists have thought up to inhabit the universe.

Physicists began with ordinary matter. (Everybody knows what that is.) About 50 years ago, difficulties with the electrical behavior of ordinary matter led P.A.M. Dirac to postulate the existence of what came to be called antimatter. Antimatter is a kind of mirror image of ordinary matter — if a given particle has a positive charge, for example, its antiparticle has a negative charge.

Shadow matter, or rather the prediction of its existence, arises from recent efforts to find a theory by which all of physics can be described in a single mathematical framework. One of the things it could do for astrophysics is explain the dynamics of galaxy clusters and cause the geometric closure of the universe. Shadow matter, though invisible, may have all the properties and behavior of ordinary matter, and so form a world that "shadows" the one we know, or it may differ in some ways. That question is not yet settled, according to Edward W. Kolb, David Seckel and Michael S. Turner of the Fermi National Accelerator Laboratory in Batavia, Ill., who present a review of the subject in the April 4 NATURE.

What is clear is that shadow matter interacts with ordinary matter only by gravity, which means hardly at all. According to these authors, a citizen could be sitting in the middle of a mountain of shadow matter or at the bottom of an ocean of it and never know it. Nevertheless, shadow matter could have interesting cosmological and astrophysical consequences.

The theories that primarily predict shadow matter are the so-called superstring theories (SN: 5/4/85, p. 277). In their mathematical formulations in the past, physicists have found it convenient to treat material bodies as if they were dimensionless geometric points. Isaac Newton did it for the sun and the planets, and the first physicists who had to consider subatomic particles did it for them.

Lately the complexities of dealing with a theory in which subatomic particles are made out of basic objects called quarks have led some theorists to opt for a theory in which subatomic particles are represented by strings: geometric constructs that have length but no breadth or depth. These are string theories, and a development that carries them into more than four dimensions is called superstring.

Some theorists prefer to imagine that the universe has more than the three space dimensions and the one time dimension that we see (SN: 7/7/84, p. 12). For the superstring theories, 10 seems to be optimum number of dimensions, according to Michael B. Green of Queen Mary College of the University of London, writing in the same issue of NATURE. To make a 10-dimensional theory compatible with the world we see, theorists "compact" the six extra dimensions. That is, they postulate that space is so sharply curved in those directions that an object setting out in one of them will return to its starting point after a microscopically short trip, about $10^{-35}$ of a meter. Neither we nor any instrumentation we have could notice such excursions, so the extra dimensions remain beneath our ken.

Cumbersome as it may sound, Green calls this procedure the likeliest way to a theory that unites gravitational phenomena with those of electromagnetism and those of the subatomic domain. It would thus provide a unified description of all of physics. With it, however, it brings shadow matter.

Shadow matter would begin at the big bang with ordinary matter. In the early epoch, when the force of gravity dominates the universe, ordinary and shadow matter would be well mixed. Eventually nongravitational forces would become dominant. These forces would act separately on matter and shadow matter, which would then become segregated from each other.

According to Kolb, Seckel and Turner, the universe could be articulated into galaxies and shadow galaxies, or there might be regions of ordinary and shadow matter within a single galaxy. There might be stars and shadow stars. A number of stars that we see have dark companions, and Kolb, Seckel and Turner suggest that some of these companions could be shadow stars.

Exactly how shadow matter relates to ordinary matter depends on assumptions made in the structure of the theory, and here Kolb, Seckel and Turner engage in some "what if" arguments. Suppose, they say, the sun has as much shadow matter as ordinary matter. Then the sun would be at once a star and a shadow star, each burning its own kind of hydrogen. From what we observe of the sun's physical processes, this cannot be true, even if it is possible that shadow matter and ordinary matter could be segregated into such small clumps. The possibility of a shadow planet — which we would not see — is dismissed also. The behavior of the solar system makes it unlikely that there are any sizable unseen bodies. However, Nemesis — the postulated stellar companion to the sun (SN: 9/1/84, p. 134) — could be a shadow star. And these arguments do not rule out the existence somewhere of a shadow solar system going unobservably about its affairs.

Today we would find it extremely difficult to determine the presence of shadow matter, but in the earliest moments of the universe, when gravity dominated, shadow matter would interfere with such processes as the formation of ordinary subatomic particles (protons, neutrons and their relatives) and ordinary atomic nuclei. The things we know about what those formation processes have left to us set constraints on how much shadow matter there can be. One thing that comes out is that there is not an exactly parallel shadow world: There is not for every particle (proton, neutron or one of their relatives) a corresponding shadow particle to second it. In fact, ordinary matter should have a slight but definite predominance.

If the microscopic physics — the subatomic behavior — of shadow matter is also not exactly symmetric to that of ordinary matter, it is possible that primordial shadow matter could disappear by annihilation reactions with shadow antimatter or by decay to ordinary matter so soon after the big bang that it would no longer be interesting. On the other hand, if there is at least one stable shadow particle that has mass, does not decay and avoids annihiliation, it could be that relict shadow matter contributes a good deal to the present gravitational dynamics of the universe. Astrophysicists who study the behavior of galaxies are convinced that there is a good deal of unseen matter contributing to gravitational forces. Kolb, Seckel and Turner suggest that shadow matter could be that unseen component. □