de Sitter Cosmology Reinterpreted

Spherical light waves independent of the motion of the frame of reference of the observer are obtained by assigning to the æther fluid three effects: (I) dilation of times, (ii) contraction of lengths in the direction of æther motion, and (iii) a velocity-dependent refractive index. Applying to constant units time dilation and length contraction appropriate for the free-fall velocity field of a Newtonian potential field, one obtains coordinate-dependent units (unit fields) in terms of which measurements obey the laws of geometry for flat Minkowski space-time. The Newtonian model of a universe, namely a uniformly dense sphere with finite radius, provides unit fields (derived from free-fall velocity) whose transformation to constant units changes Minkowski geometry to de Sitter geometry. In order to derive de Sitter space-time with uniform mass density from the Einstein field equations it is necessary to replace matter source term kT_{ab} *by the cosmological term* Λg_{ab}*. Then a single physical constant L specifies a Universe, which is reasonable if a Universe is defined with respect to mass M as absorber* $\Re(M)$ *of æther disturbances from M when M is accelerated. The exact distribution of matter surrounding M does not affect the gravitational potential* Φ_o *at M in the rest frame of M because the boundary surface of the Universe (a horizon) adjusts so as to maintain constant* Φ_o*. The same is true for another mass* M'*. A universe, so defined, is one of an infinity of Universes, each of which is an inertially isolated system in an infinite Cosmos. The redshift is shown to be capable of different interpretations, including Doppler-gravitational and "tired light." Mass density of the Universe is that of vacuum fluctuations whose positive divergent electromagnetic energy density is renormalized by divergent negative gravitational self potential energy to a finite negative value. Thus a mass falls outwards in the Newtonian Universe with negative mass density. Energy conservation demands that matter be created when mass in highly degenerate stars attains the negative energy vacuum state. It is shown how entropy decreases with the onset of degeneracy in stars.*

Introduction

The aim in this short letter is to point out that the conceptual basis for the general theory of relativity, and consequently general relativistic cosmologies, was not understood either by its originator, Einstein, or by those who followed. Einstein failed to appreciate that his theory rested on a convention—that of measurement in terms of constant units, which means units at a fixed world point, that of the observer.

The assumption of constant units is but one of an infinity of possible conventions, because the units in which axiomatic quantities (time and the three components of length) are measured are of necessity arbitrary. Constant units are specified by natural standards at a fixed world-point, that of the observer. However, one might equally well specify units by natural standards positioned at the world point of each infinitesimal element of the system under observation. Then, because gravity affects both system and units equally, the measures obtained are independent of gravity and they obey the laws of geometry for flat Minkowski space-time of special relativity. Information about geometry has been transferred to unit fields (coordinate dependence of units for time and three components of length implies that each unit becomes a unit field).

When applying time dilation to clocks and length contraction to measuring rods in order to explain the null results of æther drift experiments, Lorentz, Fitzgerald, Poincaré (LFP) and others were changing from one set of uniform unit to another set. When a gravitational field is present, the units are no longer uniform, and it will turn out that the application of time dilation and length contraction for the free-fall velocity field for a given Newtonian gravitational potential field provides a set of unit fields in terms of which measures obey the laws of geometry for Minkowski space-time.

Some of these ideas have been reported previously (Browne 1976, 1994a,b,c), but they are not generally recognized. Their significance for cosmology is considered in this paper. It is found that the Einstein space-time equivalent to the cosmological gravitational field of Newtonian cosmology is de Sitter space-time. One has the choice of Newtonian cosmology with unit fields or of de Sitter space-time with constant units, the two descriptions being exactly equivalent This equivalence is particularly illuminating for the interpretation of the Hubble redshift, which will emerge in different guises depending on the choice of reference system, which is arbitrary.

Null Results of Æther Drift Experiments

The Michelson-Morley experiment compares round-trip transit times over two paths of lengths $L_\parallel$ and $L_\perp$ which are respectively parallel and perpendicular to æther velocity $\mathbf{v}_g$. Along $L_\parallel$ the expected time was $L_\parallel/(c+v_g) + L_\parallel/(c-v_g)$ and along $L_\perp$ it was $2L_\perp/c(1-v_g^2/c^2)^{1/2}$. Introducing $\vec{b}_g = \mathbf{v}_g/c$ and $g_g = (1-b_g^2)^{-1/2}$, the expected times are respectively $2g_g^2 L_\parallel/c$ and $2g_g L_\perp/c$. The null result was explained by LFP and others by postulating that motion of matter relative to the æther fluid contracts dimensions parallel to æther velocity $\mathbf{v}_g$, and leaves unchanged dimensions normal to $\mathbf{v}_g$. We take this additional effect into account by writing $L_\parallel \to L_\parallel^* = L_\parallel/g_g$ and $L_\perp \to L_\perp^* = L_\perp$. Then predicted round trip times become $\Delta t_\parallel = 2g_g L_\parallel/c$ and $\Delta t_\perp = 2g_g L_\perp/c$.

There remains an æther factor g_g in $\Delta t_\parallel$ and $\Delta t_\perp$. The much later Kennedy-Thorndike experiment showed that both transit times are $2L/c$ rather than $2g_g L/c$. Hence, a second new effect must be postulated. Æther motion must dilate clock periods in accordance with $\Delta t \to \Delta t^* = g_g \Delta t$. Then $\Delta t_\parallel = 2L_\parallel/c$ and $\Delta t_\perp = 2L_\perp/c$.

There remains the question of whether the times $L_\parallel^*/(c+v_g)$ and $L_\perp^*/(c-v_g)$ are each equal to $g_g L_\parallel/c$ or whether they sum to $2g_g L_\parallel/c$ without being equal, which is the question of one-way light velocity. If the terms are equal, then a spherical light wavefront emitted from a point appears to be a spherical wavefront with respect to all frames of reference in uniform relative motion. Such a concept has always been difficult to reconcile with an æther. However reconciliation is possible if we assign to the æther a velocity-dependent refractive index,

$$n = 1 + \frac{\vec{b}_g \mathbf{c}}{c} \tag{1}$$

When all three new effects are included, we have the following:

$$c + v_g \to \frac{c_\parallel^*}{n_{\parallel+}} + v_g = (1 - b_g^2)\frac{c}{n_{\parallel+}} + v_g = c$$
$$c - v_g \to \frac{c_\parallel^*}{n_{\parallel-}} - v_g = (1 - b_g^2)\frac{c}{n_{\parallel-}} - v_g = c \tag{2}$$

$$\frac{c}{\left(1-b_g^2\right)^{1/2}} \to \frac{c_\perp^*}{n_\perp}\left(1-b_g^2\right) = \frac{c}{n_\perp} = c$$

where c^* is obtained from c by contracting light wavelength and dilating light period. A refractive index tensor could be defined to include the change $c \to c^*$.

Einstein chose to evade the problem rather than resolve it. He postulated that light velocity remains constant with respect to all frames of reference in uniform relative motion, and he postulated also that physical laws have the same form with respect to such frames. The laws of mechanics were modified to make them consistent with these postulates, and the modifications agreed with experiment. Maxwell's equations were already in the correct form, so that his postulates were always implicit in these equations. Because æther parameters no longer entered the equations, the fashionable view was that an æther did not exist. The possibility of deriving the same modifications to physical laws on the basis of unrecognized æther effects was not pursued, with occasional exceptions (Ehrlichson 1973, Selleri 1993, Wilhelm 1993).

Units Convention Determines Space-Time Geometry

Unwittingly, Einstein adopted the convention of constant units, specified by natural standards at a fixed world point P (Browne 1976). Measurements on a system remote from P can be quantified in terms of units at P by the Milne (1935) procedure. A "particle observer," who is equipped with only a clock and a goniometer (for measuring directions) assigns to a radar reflection at a remote event time coordinate $T = (t_1 + t_2)/2$ and distance coordinate $X = c(t_2 - t_1)/2$, where t_1 and t_2 are times of emission and reception of the radar signals. Let particle-observer O send to particle-observer O′ signals spaced by $\mathrm{d}t_1$, which return with spacing $\mathrm{d}t_2$ after reflections at O′. The return signals can inform O of the time separation $\mathrm{d}t'$ of the reflections according to the clock of O′. Thus O has a measure of the Doppler ratio $D = \mathrm{d}t'/\mathrm{d}t_2$ of O′ to whom he attributes velocity $V = X/T$, and similarly O′ has a measure of the Doppler ratio $D' = \mathrm{d}t_1/\mathrm{d}t'$ of O to whom he attributes velocity $V = X'/T'$. The assumption $D = D'$ suffices to relate $(\mathrm{d}X, \mathrm{d}T)$ to $(\mathrm{d}X', \mathrm{d}T')$ and the relation turns out to be the Lorentz transformation. Constancy of c is assumed when defining X or X', implying constant units. The distance between events (X_A, T_A) and (Y_B, T_B) can be measured by sending a light signal over the path $P \to A \to B \to P$, and it can also be worked out from given laws of geometry, knowing the angle $\mathrm{A\hat{P}B}$. Thus the events A and B lie on a space-time of pre-determined geometry.

An alternative convention for units is to transport standards from P to all field points, so that we replace four constant units by four unit fields. Measurements now are made by measuring an infinitesimal increment of the system with respect to units at the world point of that infinitesimal element. Because units and the system now are equally affected by gravity, the measures obtained are independent of gravity, so that they obey the laws of geometry for flat space-time. Now information about gravity resides in the unit fields. The unit fields can be obtained by applying length contraction and time dilation appropriate for æther velocity field $\mathbf{v}_g(\mathbf{r}, t)$ to the units at P (before transportation, making $\mathbf{v}_g(\mathbf{r}, t)$ a possible gravitational field variable. We identify $\mathbf{v}_g(\mathbf{r}, t)$ with free-fall velocity field in a given Newtonian gravitational potential field, where "free-fall velocity" is that acquired in linear motion from reference potential f_o to field potential $f(\mathbf{r}, t)$.

de Sitter Cosmos from Transformation of Unit Fields

There is an infinity of possible choices for the units convention. The Einstein and LFP approaches choose conventions with special advantages: units independent of gravity in the former case and geometry independent of gravity in the latter case. For a general convention, gravity would affect both units and geometry. In order to express arbitrary unit fields, we demand general covariance with respect to anholonomic (non-integrable) transformations of coordinates of type (Browne 1976)

$$dx^{-a} + X_b^a dx^b \qquad (3)$$

Here dx^b for reference system 1 of space-time A project, via x^5 coordinate curves, onto dx^{-a} for reference system 2 of space-time B. When $X_b^a = dX^a/dx^b$ equations (1) become integrable, and reference systems 1 and 2 belong to the same space-time. Choice of unit fields fixes the geometry of space-time, and conversely, choice of space-time geometry fixes the unit fields (Browne 1976).

For example. consider as a model of the universe a sphere of mass of uniform density r_o and of radius R, in which the Newtonian gravitational potential is

$$f(r) = -2pGr_oR^2\left(1 - \frac{r^2}{3R^2}\right) \qquad (4)$$

inertial mass density Kr_o corresponds to gravitational mass density r_o, where K is a constant with dimensions which usually is assigned value unity by choice of the gravitational constant G. We identify Kr_oc^2 with energy density of zero-paint radiation after renormalization to include self-gravitational potential energy (Browne 1994a,b,c). The free-fall velocity in the potential field (4) is v_g where

$$\frac{Kv_g^2}{2} = f(r) - f(0) = \frac{2pGr_or^2}{3} \qquad (5)$$

since unit inertial mass is K. Thus

$$\frac{v_g}{c} = \frac{r}{R}, \quad 4pGr_oR^2 = 3Kc^2 \qquad (6)$$

The total mass in the Newtonian universe is $M = 4pr_oR^3/3$, so that (6) yields

$$\frac{GMm}{R} = Kmc^2 \qquad (7)$$

which states that gravitational potential energy cancels rest energy for any mass m at $r = R$. This is the condition for a black hole, enabling us to regard R as the event horizon of a black hole from an external viewpoint.

Knowing the free-fall velocity field (6) we obtain the unit fields by applying time dilation and length contraction to constant units appropriate for velocity field (6). Introducing spherical polar coordinates (r, q, f), and defining $\mathrm{d}s^2 = \mathrm{d}q^2 + \sin^2 q\,\mathrm{d}f^2$, measuring rods in the direction $\vec{b}_g$ are contracted by the factor g_g, rods normal to $\vec{b}_g$ are unchanged and clock periods are dilated by factor g_g, where $g_g = \left(1 - b_g^2\right)^{-1/2} = \left(1 - r^2/R^2\right)^{-1/2}$. Measures obtained in terms of these coordinate-dependent units are changed by the reciprocal factors. Denoting measures for the coordinate-dependent units by $(\mathrm{d}\bar{t}, \mathrm{d}\bar{r}, \bar{r}\mathrm{d}\bar{s})$ and measures for the constant units by $(\mathrm{d}t, \mathrm{d}r, r\mathrm{d}s)$, the units transformation (3) yields

$$\mathrm{d}\bar{t} = \left(1 - \frac{r^2}{R^2}\right)^{1/2}\mathrm{d}t, \quad \mathrm{d}\bar{r} = \left(1 - \frac{r^2}{R^2}\right)^{-1/2} r, \quad \bar{r}\mathrm{d}\bar{s} = r\mathrm{d}s \qquad (8)$$

Invariance of the element of interval ds under (8) yields

$$\begin{aligned}\mathrm{d}s &= c^2\mathrm{d}\bar{t} - \mathrm{d}\bar{r}^2 - \bar{r}^2\mathrm{d}s^2 \\ &= \left(1 - \frac{r^2}{R^2}\right)c^2\mathrm{d}t^2 = \left(1 - \frac{r^2}{R^2}\right)^{-1}\mathrm{d}r - r^2\mathrm{d}s^2\end{aligned} \qquad (9)$$

which is de Sitter space-time.

Transformation (8) introduces a reference system in a space-time of different geometry because it cannot be integrated. Einstein restricted general covariance to those reference systems which are obtained by integrable transformations of coordinates, which is to say reference systems belonging to the same space-time. In effect we have projected coordinate elements from a curved space-time to a flat space-time.

Modified Einstein Equations

De Sitter space-time has been known and explored as a solution of the Einstein field equations,

$$R_{ab} - \tfrac{1}{2} R g_{ab} = k T_{ab} \tag{10}$$

where R_{ab} is the contracted Riemannian curvature tensor for metric tensor g_{ab}, $R = g^{ab} R_{ab}$ and T_{ab} is the stress-momentum-energy tensor for a fluid medium given by

$$T_{ab} = \left(K\rho_o c^2 + p_o\right) v_a v_b - p g_{ab} \tag{11}$$

where $v^a = \mathrm{d}x^a / \mathrm{d}s$ and p is pressure. The assumption of spherical symmetry and static conditions yields de Sitter space-time as the solution of (10) only provided that $K\rho_o c^2 + p_o = 0$, so that $\rho_o = p_o = 0$. This has always been thought to imply an empty Universe. The derivation of de Sitter space-time (9) from a units transformation, however, is for a universe with constant mass density ρ_o.

Apart from this criticism, there is a more serious criticism of (10). Equations which obey the Principle of General Covariance can be expected to apply only to an isolated system, and since (10) makes no restrictions on the choice for $\rho_o\left(x^a\right)$ or $p_o\left(x^a\right)$ it would appear that one is free to apply (10) to non-isolated systems.

Mach's Principle attributes inertial force to background matter of the universe. In the spirit of the Wheeler-Feynman absorber theory for radiation (Wheeler and Feynman 1945, Browne 1969) we must attribute inertial force on mass M to a disturbance in the æther fluid which propagates from the accelerated mass until it is absorbed by matter of the surrounding universe, this disturbance constituting the advanced gravitational field of the absorber. The system of M and absorber $\Re(M)$ together constitute a perfectly isolated system. The distribution of matter in $\Re(M)$ does not affect the inertial force because the boundary surface of the absorber (in an infinite Cosmos) adjusts so that the gravitational potential Φ_o due to the absorber at the position of M and in the rest frame of M is a universal constant. A single universal constant therefore specifies a Universe. A "Universe" is defined only with respect to a mass M, and its boundary is a horizon with respect to M. For another mass M' distribution of surrounding matter is different and the horizon is different, but the potential at M' is still Φ_o. Such a definition of a Universe as an inertially isolated system has the consequence that a single universal constant specifies the source term for the equations (10). For this reason we consider that the term kT_{ab} should be replaced by Einstein's cosmological term Λg_{ab}, where Λ is a constant. When Einstein introduced the cosmological term it was in addition to T_{ab}, not instead of it.

For the above three reasons we consider that the Einstein field equations should be modified to $R_{ab} = \tfrac{1}{2} R g_{ab} = -\Lambda g_{ab}$, which simplifies to

$$R_{ab} = \Lambda g_{ab} \tag{12}$$

in which only geometrical quantities appear apart from the constant Λ. Now we have $R = 4\Lambda$, so that the curvature invariant is a constant. Space-times of constant curvature can always be embedded in a five-dimensional Euclidean space-time (Pauli 1958). The static spherically symmetric solution of (12) is (Tolman 1934)

$$\begin{aligned} \mathrm{d}s^2 &= \gamma_g^{-2} c^2 \mathrm{d}t^2 - \gamma_g^{2} \mathrm{d}r^2 - r^2 \mathrm{d}\sigma^2 \\ \gamma_g &= 1 - \frac{R_S}{r} - \frac{r^2}{R^2} \end{aligned} \tag{13}$$

where $\Lambda = 3/R^2$ and where R_S is an integration constant. When R_S/r is negligible (13) becomes the de Sitter metric (9) and when r^2/R^2 is negligible it becomes the Schwarzschild metric for some very small mass.

One notes that $r > R$ or $r < R_S$ makes γ_g imaginary, and in units transformation (8) $\mathrm{d}t^2$, $\mathrm{d}r^2$ and hence $r^2 \mathrm{d}\sigma^2$ all change sign, which requires that $\mathrm{d}\tau^2$ changes sign (where τ is proper time) in order to preserve the signature of the metric. Thus $\tau \to i\tau$. Crossing the boundary radii makes time imaginary. Clearly R and R_S are upper and lower bounds to our awareness. Both bounds are black hole radii, our awareness being external to one black hole and internal to another.

The Hubble Redshift in Different Guises

The velocity of a light signal traveling in the radial direction in de Sitter space-time, as found by putting $\mathrm{d}s = \mathrm{d}\sigma = 0$ in (9), is

$$c(r) = c\left(1 - \frac{r^2}{R^2}\right) \tag{14}$$

The geodesic equations for radial motion ($\mathrm{d}\sigma = 0$) yield

$$\begin{aligned} \frac{\mathrm{d}t}{\mathrm{d}\tau} &= \left(1 - \frac{r^2}{R^2}\right)^{-1} \\ \frac{\mathrm{d}r}{c\,\mathrm{d}\tau} &= \pm\frac{r}{R} = \pm\frac{v}{c(r)} \end{aligned} \tag{15}$$

where $v = \mathrm{d}r/\mathrm{d}t$. Units transformation (8) converts $c(r)$ to c, so that (15) agrees with (6).

A wave crest emitted by a source at radial distance r at time t_1 is received at the origin at time t_2, where

$$t_2 - t_1 = \int_0^r \frac{\mathrm{d}r}{c(r)} \tag{16}$$

By taking differentials, solving for dt_2/dt_1, and converting to $d\tau_2/d\tau_2$ which is the reciprocal of the frequency ratio ν_2/ν_1 we find

$$\frac{\nu_1 - \nu_2}{\nu_1} = \frac{r}{R} = \frac{v}{c(r)} = \frac{v}{c}\frac{dt}{d\tau} \tag{17}$$

Thus, with respect to reference system (r,t) matter of the universe expands/contracts with velocity (15) and the Hubble redshift has a Doppler factor v/c and a gravitational factor $dt/d\tau$. Whether we obtain expansion or contraction must depend on the sign of particle mass in relation to the sign of the mass density $K\rho_o c^2$ identified with zero-point radiation. For expansion ρ_o must be negative, which is to say that the sum of positive electromagnetic zero-point energy density and negative gravitational self potential energy density (both divergent) is negative (Browne 1994a,b,c).

However, we may choose a reference system $(\bar{r},\bar{t})$ with respect to which matter of the Universe is stationary, and now the Hubble redshift emerges in a different guise. The coordinate transformation,

$$\bar{r} = r\left(1 - \frac{r^2}{R^2}\right)^{-1/2} \exp\left(-\frac{ct}{R}\right) \tag{18}$$

changes the metric (9) into the form

$$\mathrm{d}s^2 = c^2 \mathrm{d}t^2 - \exp\left(\frac{2c\bar{t}}{R}\right)\left(\mathrm{d}\bar{r}^2 - \bar{r}^2 \mathrm{d}\sigma^2\right) \tag{19}$$

which is said to represent a steady state because (19) is unchanged under

$$\bar{t}' = \bar{t} - \bar{t}_o, \quad \bar{r}' = \bar{r}\exp\left(\frac{c\bar{t}_o}{R}\right) \tag{20}$$

which introduces a new time origin $\bar{t}_o$.

Now radial light velocity, obtained by $\mathrm{d}\sigma = \mathrm{d}s = 0$ in (19), is

$$c(\bar{t}) = c\exp\left(-\frac{c\bar{t}}{R}\right) \tag{21}$$

and the geodesic equations are,

$$\frac{d\bar{r}}{dt} = 0, \quad \frac{d\bar{t}}{dt} = 1 \tag{22}$$

which imply that matter is at rest with respect to the $(\bar{r}, \bar{t})$ reference system. In fact, (18) is an integral of (15) in which $\bar{r}$ is an integration constant.

Now the time $\bar{t}_1$ of emission of a wave crest by a source at distance *r* is related to the time of reception at the origin by

$$\bar{r} = -\int_{\bar{t}_1}^{\bar{t}} c(\bar{t})d\bar{t} \tag{23}$$

Taking differentials gives $0 = c(\bar{t}_1)d\bar{t}_1 - c(\bar{t}_2)d\bar{t}_2$ and hence

$$\frac{n_2}{n_1} = \frac{d\bar{t}_1}{d\bar{t}_2} = \exp\left(-c\frac{\bar{t}_2 - \bar{t}_1}{R}\right) = \exp\left(-\frac{\ell}{R}\right) \tag{24}$$

where $\ell = c(\bar{t}_2 - \bar{t}_1)$. For small redshifts we obtain Hubble's law,

$$\frac{n_1 - n_2}{n_1} = 1 - \exp\left(-\frac{\ell}{R}\right) \cong \frac{\ell}{R} \tag{25}$$

Successive wavecrests propagate with constant separation dr, but the velocity with which they leave the source $c(\bar{t}_1)$ is higher than the velocity with which they enter the detector $c(\bar{t}_2)$ so detector frequency is less than emitter frequency. By using (20) to continuously adjust the time origin, it is possible to maintain constant light velocity during propagation, but then frequency varies continuously, giving the Hubble effect a "tired-light" interpretation. How this tired-light mechanism operates in detail has been discussed elsewhere (Browne 1962, 1994a,b).

Whereas the Hubble effect receives a Doppler-gravitational interpretation for reference system (r,t), the interpretation for reference system $(\bar{r}, \bar{t})$ is a tired-light effect. One reference system is not preferred to another, so either interpretation must be valid (Browne 1979). Other reference systems introduce yet other interpretations for the Hubble effect. For example, transformation

$$ct' = R\exp\left(-\frac{c\bar{t}}{R}\right) \tag{26}$$

applied to metric (19) introduces the conformally flat metric

$$ds^2 = \left(\frac{R}{ct'}\right)^2 \left(c^2 dt'^2 - dr^2 - r^2 ds^2\right) \tag{27}$$

Radial light velocity is *c*. At any epoch t' matter in this universe has a velocity which depends on t', so that the velocity of source at light emission differs from that of detector at light reception and there is a change of gravitational potential for the same reason. Thus the redshift is a mixture of Doppler and gravitational effects.

Entropy Decrease and Matter Creation

Despite expansion/contraction of the Universe predicted by (15) the radius *R* of the universe interpreted as a perfectly isolated system remains a constant. Presumably matter is created at a rate sufficient to balance the loss of matter by expansion. We have a precise mechanism for matter decay, namely conversion of mass into radiation by fusion of light elements in the interior of stars, and conversion of stellar and other radiation of arbitrary spectrum into blackbody radiation by graviton scattering (Browne 1962), but there exists no known mechanism for matter creation.

How to reconcile a steady-state universe with the continual degradation of the quality of energy *i.e.* equipartition of at least some energy among an increasing number of degrees of freedom (entropy increase) was a problem which preoccupied Nernst (1937). Nernst postulated matter creation in order to decrease entropy, thus avoiding what was called a "heat death" for the universe, but he offered no mechanism for creation.

Previously (Browne, 1975) I have argued that the equation of state of degenerate gas does not change from $p = n_e kT$ with onset of degeneracy, because pressure should be defined as change of momentum flux per unit area rather than simply momentum flux per unit area. In an electron-degenerate star, only those electrons which occupy states within kT of the Fermi level E_F are free to enter unoccupied states, and hence only this fraction $\Delta n_e / n_e$ of the total density n_e is able to change momentum. Only this fraction makes collisions, the others having motions so ordered that they avoid collisions (*e.g.* the 92 electrons circulating around the nucleus of the uranium atom never collide with each other). Those electrons which can collide in a degenerate gas have mean kinetic energies $\cong E_F$ which exceeds kT by the factor E_F / kT. Since $\Delta n_e / n_e \approx kT / E_F$ the factor by which energy kT is exceeded is canceled by the factor by which the number of colliding electrons is reduced, yielding unchanged equation of state

$$p = \Delta n_e E_F = n_e kT \tag{28}$$

Here thermal energy is being shared among a decreasing number of particles, which represents a decrease of entropy.

The onset of electron degeneracy is followed after sufficient cooling by the onset of proton degeneracy and the neutron star phase. As cooling proceeds, entropy is lowered progressively and a zero-entropy state of matter is approached. Evidently, the degenerate star, in its ultimate state, is a component of the æther from which matter can spontaneously arise.

As mentioned following Eq. (17), zero-point radiation is renormalized to a finite negative value $Kr_o c^2$ (where r_o is negative). In such a Universe, a mass falls outwards rather than inwards. As matter in degenerate stars progresses to increasingly negative energies (implying densities exceeding black-hole density) matter in positive energy states must appear spontaneously in order to conserve energy. Such a Universe has zero total energy. As ultradegenerate stars cool toward absolute zero, their energy becomes increasingly negative, and matter must appear spontaneously in non-degenerate states of positive energy in order to maintain zero total energy.

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