At Swarthmore College, Mr. Louis Fussell, instructor in electrical engineering and Mr. Ross W. Marriott, instructor in mathematics, have been promoted to assistant professorships. Mr. H. L. Ward, who has been assistant at Yale University, has been appointed instructor in chemistry.

Mr. George P. Paine, of Ripon College, has been made assistant professor of mathematics at the University of Minnesota.

Dr. Jonathan T. Rorer, of the Central High School, Philadelphia, has been called to the headship of the mathematical department of the new William Penn High School for Girls, of the same city.

The chair of botany at Birmingham, vacant by the retirement of Professor Hillhouse, has been filled by the appointment of Dr. G. S. West, who for the past four years has been lecturer in botany at the university.

Mr. James Colquhoun Irvine, Ph.D. (Leipzig), D.Sc. (St. Andrews), has been appointed to the chair of chemistry in the University of St. Andrews in place of Professor Purdie.

Discussion and Correspondence

The Fundamental Laws of Matter and Energy

To the Editor of Science: In a late number of Science (April 23, 1909) Professor Speyers has raised some objections to the system of non-Newtonian mechanics which I recently published.[1] While some of these objections are due to misunderstanding of the method employed in developing the new system, others of an *a priori* character are based apparently upon a certain feeling of repugnance to the view that the velocity of light in vacuo possesses a unique significance, as the limit of all possible velocities in a material system. This feeling, which has been expressed by numerous critics of non-Newtonian mechanics, I should like to discuss briefly. I will take this opportunity also to present in a new and perhaps simpler way, the principles involved in the development of the new system of mechanics.

[1] *Technology Quarterly*, June, 1908; *Philosophical Magazine*, 16, 705.

We may base our whole argument merely upon four empirical laws, of which the first two are universally accepted and form an essential part of the foundation of physical science. The other two are more specific in character, but it is hardly likely that their validity will be questioned by any one.

The first is the law of conservation of mass. If a system gains in mass, its environment must lose in mass by the same amount.

The second law states that if the center of mass of a given system is at rest, it can not be set in motion except through the agency of an external force; in other words, if the center of mass of an *isolated* system is at rest, it will remain at rest.

The third law was deduced by Maxwell from electromagnetic principles, by Boltzmann from thermodynamics, and has been accurately verified experimentally by Nichols and Hull. It concerns the mechanical impulse experienced during the absorption or emission of light. If a body emits a beam of parallel light, it acquires momentum in the opposite direction and the momentum acquired is equal to E/V; where E is the quantity of energy emitted, and V is the velocity of light.

The fourth law has always been tacitly assumed and I name it here only to show with particularity the whole empirical basis upon which the system of non-Newtonian mechanics rests. This law states that if a body suffers a mere loss of energy through radiation, and if then the same amount of energy is returned to it by thermal conduction, or by an electric heater, or by friction, or in any other such way, the system will return to its original condition.

Let us now consider, isolated in space, a body at rest. For an instant this body emits a beam of parallel light directly away from its center of mass. As a consequence of the pressure of the emitted light, the body begins to move in the opposite direction, acquiring momentum which is equal to E/V, E being the energy of the small quantity of radiation which is now traveling away from the original center of mass of the system with a velocity V.

If the velocity acquired by the body is v

and its mass is now m', then according to the law stated above,

$$m'v = \frac{E}{V}. \quad (1)$$

From our fundamental law concerning the center of mass, it is obvious that, when the body begins to move, some mass must move in the opposite direction in order to keep the center of mass in its original position. But since nothing is moving in this direction except the small quantity of radiant energy which was emitted, this radiant energy must itself possess a mass m which is to the mass m' inversely as the distances, at any instant, of m and m' from the original center of mass. These distances are proportional to the two velocities and thus,

$$\frac{m}{m'} = \frac{v}{V}. \quad (2)$$

Combining equations (1) and (2) gives

$$m = \frac{E}{V^2}. \quad (3)$$

Therefore a beam of light possesses a mass which is equal to its energy divided by the square of the velocity of light.

By the conservation law the mass associated with the radiant energy must come from the emitting body, the latter therefore loses mass in proportion to the energy it loses. On the other hand, if the same quantity of energy as was emitted is now returned to the body in some other way, say by thermal conduction, the original internal condition of the body being restored, it will regain its original mass. It is evident, therefore, that when a body gains energy in any way, it simultaneously gains mass according to the simple law

$$dm = \frac{dE}{V^2}. \quad (4)$$

This equation connecting the mass of a body with its content of energy is the basic equation of non-Newtonian mechanics. From this the other theorems follow at once. Thus it is obvious that if a body in motion has more energy than one at rest, it must also have a greater mass. Hence, we are led directly, as shown in my paper, to the equation

$$\frac{m}{m_0} = \frac{1}{\sqrt{1 - \frac{v^2}{V^2}}}. \quad (5)$$

where m is the mass of the body moving with velocity v, and m_0 is its mass at rest.

This is the only equation of non-Newtonian mechanics that has been subjected to a direct experimental test. In my paper attention was called to the general agreement between the demands of equation (5) and the experiments of Kaufmann on the mass of the rapidly moving β particles emitted by radium, but some of the differences between the observed and calculated values seemed to some scientists too great to ascribe to experimental error. However, this question is now definitely settled by the recent work of Bucherer,[2] who investigated the same problem by a more accurate method. His results on the change of mass with the velocity are in striking agreement with our equation.

Since therefore non-Newtonian mechanics is based solely upon laws which have been universally accepted, and has been further verified directly by this decisive experimental test, the new system seems to be upon a thoroughly secure experimental foundation.

It is evident in equation (5) that m approaches infinity when v approaches the velocity of light. Hence a body moving as fast as light would have infinite mass and infinite energy. This is the conclusion which to some scientists has seemed incredible. They suggest that if we had started with an observation on the pressure of sound instead of the pressure of light, we might have been led to the conclusion that the velocity of sound is the maximum possible velocity. Of course, if this idea could be substantiated, it would be a very efficient *reductio ad absurdum* of the method. As a matter of fact, however, if we apply to sound energy the kind of reasoning that we have applied to radiant energy, we are brought neither to an absurdity nor to any result which is not readily predicted from the elementary principles of mechanics.

It is not that we have decided in advance

[2] *Berichte Deutsch. physik. Gesell.*, 6, 688 (1908).

to ascribe to the velocity of light this unique position. Nature forces us to a conclusion and if this conclusion is incompatible with our preconceived opinions, it is the opinions that must be changed.

Not many years ago, it was supposed to be possible to increase both heat and cold without limit, but we no longer hope to attain any temperature below —273° C. To cool any body to the absolute zero would require an infinite amount of work. Now we find likewise that it would take infinite work to bring any body to the velocity of light, and just as —273° C. became recognized first as the lowest possible temperature, then as the lowest conceivable temperature, so we must not only regard 3×10^{10} centimenters per second as the highest possible velocity, but we must so change our present ideas that this shall be the *highest conceivable velocity* in a material system.

In closing I should like to modify one of the statements in my previous paper. It was there intimated that the equations of non-Newtonian mechanics offered a means of determining absolute motion through space. In a recent paper by Mr. Tolman and myself[3] it is shown, on the other hand, that these equations maintain their full validity no matter what point is arbitrarily chosen as a point of rest.

Gilbert N. Lewis

Research Laboratory of
Physical Chemistry,
Massachusetts Institute of Technology,
June 19, 1909

Some Trends in Higher Education

To the Editor of Science: I was very much interested in the article by Mr. Marx entitled "Some Trends in Higher Education," which appeared in the issue of Science of May 14. While I believe that such investigations are of value, it seems to me that this article and others of a like nature, which have been appearing recently, show the need for more accurate and reliable statistics relating to higher education. In the great majority of cases the writers have all too often been intimately acquainted with only one institution. They have realized that in the case of this institution, well known to them, allowance had to be made for the published statistics, but they have not shown equal generosity to those institutions concerning which they knew little or nothing, and have accepted all statistics at face value. All persons connected with universities know very well, for example, how little trust is to be placed in the average comparative tables regarding the total number of students at the various institutions of learning. Nearly every larger university, by means of due selection and suppression, has made out a good case at one time or another in the attempt to show that it is the largest university in this country. These methods savor very much of some of the advertising indulged in by insurance companies, but universities and those writing about them ought to have a somewhat more scientific standard.

Mr. Marx's article is not devoid of many of the faults to which I have alluded. To cite just one instance: take, for example, the last column of table 4 on page 784. This table is supposed to give the average salary per member of the instruction staff, but surely no one having an intelligent knowledge of higher education in America can suppose that the *average* salary per year at Johns Hopkins is $1,226, or at Northwestern $835, or at Minnesota $867, or at Toronto $881.

It is not surprising to find the most erroneous conceptions prevailing about the administration of our universities, when even a responsible paper like Science publishes figures such as these noted without further explanation. Such looseness of statement does great injustice to many an institution. In the College of Liberal Arts at Northwestern University, where the salaries average lower than they do in the professional schools of the same institution, the instruction staff consists of fifty-nine persons. Their salaries for the year 1909–10 will amount to $117,450. This is an average annual salary of almost $2,000 per individual. It is a fact that no teacher in the university, who is paid at all, receives for a year's work so small a sum as $835. The low-

[3] "The Principle of Relativity and Non-Newtonian Mechanics," *Proc. Amer. Acad.*, June, 1909.