System of Units for Nuclear and Cosmic-Ray Phenomena

It has become customary, in dealing with nuclear or cosmic-ray phenomena, to measure some quantities in terms of units which are different from those used in macroscopic physics. Thus, the energy of a particle is generally measured in electron volts; the charge of a nucleus is expressed by its atomic number, i.e., in terms of the electronic charge, etc. No attempt, however, has been made so far to bring the new units into a consistent system. Such a lack of systematization has been the source of many incongruities and misunderstandings, as illustrated by the following example. The so-called energy measurements on cosmic-ray particles are usually performed by measuring the radius of curvature ρ in a magnetic field H. If we call p the momentum of the particle, e its electric charge, c the velocity of light and we measure H in gauss, e in electrostatic units, ρ, c and p in c.g.s. units, it is $H\rho=(pc)/e$. The quantity $(pc)/e$ is a potential in electrostatic units and its measure in volts is $V_p=300(pc)/e=300H\rho$. The results of magnetic deflection experiments are generally described by the quantity V_p. This quantity is often called energy, which is misleading since V_p is actually proportional to the momentum of the particle and not to its energy, although its numerical value approaches that of the energy in electron volts when the velocity of the particle approaches the velocity of light. Other authors describe a particle as having a momentum equal to V_p "electron volts." The quotation marks acknowledge the contradiction in terms, since electron volts are a measure of energy rather than momentum.

The increasing importance of the study of sub-atomic phenomena makes it very desirable to remove the above incongruities by adopting a consistent system of units. The writer wishes to point out that this can be done retaining almost all of the units already used. The suggested system is summarized in Table I.

In this system, the charge of a nucleus is measured by its atomic number, the velocity of a particle becomes identical with the quantity usually designed by β, the energy is expressed in electron volts, the momentum is the quantity V_p defined above, the mass is measured by the same number which measures the rest energy in electron volts. The units of length, of potential difference and of electric field strength are the conventional ones. The units of time, of force and of magnetic induction (deflecting field) are more unusual. They have, however, a simple meaning and could be conveniently adopted. The system has four independent units, as any consistent system describing electromagnetic as well as mechanical quantities.[1] Like in all four-units systems, both the dielectric constant and the magnetic permeability have physical dimensions. Their numerical values in vacuum are $\epsilon_0=7.0\times10^6$ e/v cm and $\mu_0=1/7.0\times10^6=1.43\times10^{-7}$ v cm/e c^2.

TABLE I. *Suggested system of units for nuclear and cosmic-ray phenomena.*

QUANTITY	SYMBOL	DEFINITION
	Fundamental Units	
electric charge	e	charge of the positive electron
potential	v	usual definition of volt
velocity	c	velocity of light
length	cm	usual definition of centimeter
	Some Derived Units	
time	cm/c	time required by the light to travel 1 centimeter
energy	ev	energy of an electron accelerated by the potential difference of 1 volt
mass	ev/c^2	mass of a particle having a rest energy of 1 electron volt
momentum	ev/c	momentum of a particle for which (total energy)^2 − (rest energy)^2 = 1
electric field strength (E)	v/cm	usual definition of volt per centimeter
force	ev/cm	force acting on an electron in a field of 1 volt per centimeter
magnetic induction (B)	v/c cm	magnetic induction of a field in which a particle with unit momentum and unit charge has a radius of curvature of 1 centimeter when traveling perpendicularly to the field (1 v/c cm = 1/300 gauss).

As a name for the unit of velocity, the word *römer* has been suggested to the writer by Professor W. H. Zachariasen. Should this name be accepted, the symbol of the unit might be changed from c to r. The system, as a whole, could be conveniently designed as system of *electron-relativistic units*, considering the two universal constants which have been chosen as units for the electric charge and for the velocity.

Professors A. H. Compton, C. Eckart and W. H. Zachariasen were kind enough to discuss with the writer the content of this note.

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[1] See, for instance, A. Sommerfeld, Ann. d. Physik **36**, 335 (1939).

Isomeric Silver and the Weizsäcker Theory

A detailed study of the 6.7-hour radioactive cadmium,[1] formed in the reaction Ag $(d,2n)$ Cd, has resulted in several new observations. This body is known to emit K- and L-conversion electrons of a 93.5 kev γ-ray; K x-rays of silver, indicating K-electron capture as well as internal conversion; and a very weak gamma-ray with an absorption coefficient in lead about equal to that of annihilation radiation. The anomalously high ratio of L- to K-conversion electrons[2] suggested that the excited state responsible for them might have an appreciable life. We have found that the electrons do come from an excited state of stable silver, which decays with a half-life of 40±2 sec. This period has been followed for 12 half-lives after chemical separation from radioactive cadmium, and its growth in the Cd solution has also been observed. The hard gamma-ray does not separate with the Ag, but about half of the x-rays do, as would be expected. We have also observed a very weak γ-ray of about 90 kev, which accompanies the 40-sec. Ag and is almost certainly the unconverted fraction of the 93.5 kev γ-ray. Bjerge and Westcott[3] have reported a 40-sec. period in Ag bombarded by Rn-Be neutrons, which has been assigned[4] to the 44-sec. rhodium period formed in a n,α reaction. Since no well-established (n,α) reactions are known for such high values of Z, and such low energy neutrons, this observation may now be interpreted by assuming an (n,n) excitation. The excited state of Ag should also be formed in (p,p), (α,α) and (x,γ) reactions.

We compared the absorption of the hard γ-rays with that of annihilation radiation from the 3.5-hr. Cu^{63}, under enough lead to reduce the ionization to less than eight percent. The Cd γ-ray is more penetrating. An experiment with coincidence counters also showed it to be for the most part a nuclear γ-ray. We found evidence for the expected Auger electrons from a sample of pure radioactive Cd, distilled in vacuum, from bombarded silver. This distillation technique should find many uses in the field of artificial radioactivity.

From the ratio of the numbers of K and L conversions, a theory proposed by one of us[5] requires a multipole order of 4 ± 0.1 for the transition between the two silver states. The measured internal conversion coefficient of 98 percent demands a similar, but not quite so precise value of this multipole order, from the theory of Dancoff and Morrison.[6] If we assume the value 4 to be correct, and calculate the lifetime of a 93.5 kev level in Ag by means of Weizsäcker's formulae corrected by Hebb and Uhlenbeck[7] to include decay by internal conversion, we obtain an expected value of 30 sec. On this theory, multipole orders of 3 and 5 would give lifetimes of about 10^{-3} and 10^{6} sec., respectively. The agreement between these three methods of computing the order indicates further that the transition is an electric rather than a magnetic 2^4 pole, so that the spin difference between the two states in silver is 4 units. In view of the approximations made in the theory, the agreement with respect to lifetime is a most encouraging check.

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Elementary Derivation of Thermal Diffusion

Thermal diffusion is usually thought not amenable to elementary derivation.[1] It may, then, be of value to point out a method of showing its existence and sign from elementary considerations. Thermal diffusion shows itself if a mixture of two gases is kept at a non-uniform temperature. It causes a gradient of the partial pressure of either gas which is observed as a partial separation of the gases. To support this partial pressure gradient the "partial gas" must experience a constant force due to collisions with molecules of the other gas. Hence there must be a continual net transfer of momentum from one gas to the other. To evaluate this one can find the momentum change suffered by a molecule of type "1" in a collision with a "2" molecule and sum over all collisions.

The result of this may be most easily understood by the following very rough treatment. Consider the heavier molecules as stationary, the light gas as composed of two streams of uniform velocities moving toward the cold and hot sides, respectively. The velocity of the stream coming from the hot side is somewhat greater than the velocity of the other stream. Each light molecule with velocity V loses its momentum to the heavy molecules at a rate $V\sigma$ where σ is the cross section for complete dissipation of momentum. Since each stream must carry the same momentum per cm^3 (to make the net particle flux zero) the momentum transfer per second of the streams is proportional to $V\sigma$. The dependence of $V\sigma$ on the velocity can be found by a dimensional argument. Let the molecules interact by an inverse sth power repulsion, $F=-K/r^s$. Then σ may depend on K, on the mass of the light molecule (strictly the reduced mass), on V, and on s. From the dimensions of these quantities it is seen that σ must be proportional to $(K/mV^2)^{2/(s-1)}$ or to $V^{-4/(s-1)}$. Thus $V\sigma$ varies as $V^{(s-5)/(s-1)}$. This gives a force supporting an excess of light component at the hot side for molecules "harder" than Maxwellian molecules ($s=5$) or at the cold side for $s<5$ and no thermal diffusion for Maxwellian molecules.

A more rigorous treatment would take account of the motion of the heavy molecules and of the distribution in velocities of both types. Denote by $f_1(\mathbf{c}_1)$ and $f_2(\mathbf{c}_2)$ the velocity distributions of the light and heavy gases, respectively, normalized to their respective particle densities. Define a cross section for momentum transfer as follows: If a uniform stream of particles of mass μ, the reduced mass of the collisions, impinges on a scattering center $F=-K/r^s$, then the total momentum transferred to the scattering center is the product of the cross section, σ, and the momentum per cm^2 of the stream. Then as before this cross section must vary with the relative velocity as $V^{-4/(s-1)}$. The momentum gained per second by the light gas is then given by the expression

$$\int\int \tfrac{1}{2}(\mathbf{p}_2-\mathbf{p}_1)f_1(\mathbf{c}_1)f_2(\mathbf{c}_2)\sigma V d\mathbf{c}_1 d\mathbf{c}_2 = C\int\int(\mathbf{p}_2-\mathbf{p}_1)f_1(\mathbf{c}_1)f(\mathbf{c}_2)V^{(s-5)/(s-1)}d\mathbf{c}_1 d\mathbf{c}_2,$$

where $\mathbf{p}_1$ and $\mathbf{p}_2$ are the momenta of the light and heavy molecules, respectively. C is positive and does not depend on the velocities. $f_1(\mathbf{c}_1)$ and $f_2(\mathbf{c}_2)$ while not Maxwellian still must obey the relationship $\int f(\mathbf{c})\mathbf{p}d\mathbf{c}=0$ since this expression divided by m is the rate of flux of molecules. Hence for $s=5$ the term in V drops out and the integral vanishes. For harder molecules the collisions of high relative velocity are more effective. The collisions of highest relative velocity are predominantly those in which the lighter molecule is coming from the hotter region and the heavier from the colder region. Thus the resulting force is such as to support a greater partial pressure of light molecules in the hot part of the gas, and conversely as before for molecules softer than $s=5$. It may also be seen from this argument that the effect must be proportional to the product of the two fractional concentrations and to the relative mass difference.

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