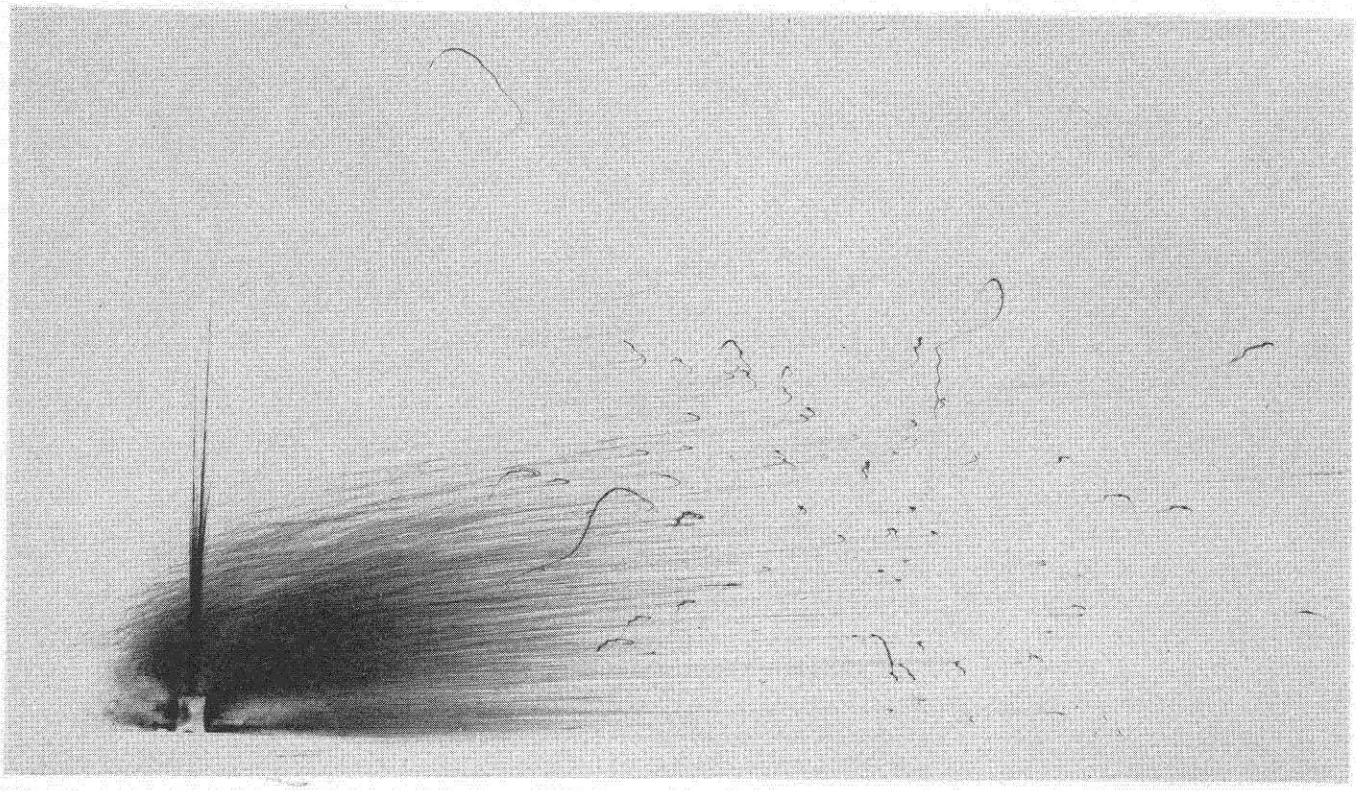


Ultrafast particles extruded from 1¼-inch copper cone liner of a commercial shaped charge, such as is used in oil-well drilling operations. Photograph was made with a rotating camera. The great plume of luminous particles whose paths appear flattened out because of the camera's rotation are fragments of the container of the shaped charge. The few particles whose tracks are almost vertical have tremendous speed; tracks are hardly bent despite fast rotation of camera.

ARTIFICIAL METEORS

A progress report on research in this field—and a look at its future.

by FRITZ ZWICKY

SOME TIME AGO tests were made with artificial meteors[1], extruded from metallic inserts in detonating *shaped charges*[2]. Experiments with these objects give the following basic information:

1) Artificial meteors in air with speeds of several kilometers per second fall into the category of motion called *ultra-flight*[3] during which either the projectile or the medium which it traverses suffers physico-chemical changes.

2) Artificial meteors expelled from cavity charges may be solid, liquid or "gaseous." Launched from high flying balloons or rockets they constitute pencil jets with possible ranges of thousands of kilometers. The observation of their trajectories and their spectra should give us information on the upper atmosphere as well as on the electric and magnetic fields at great heights.

3) Finally, artificial meteors can be imparted velocities greater than 11.2 km/sec. This suffices to have them permanently escape from the earth, if properly launched from great heights.

Using uniform explosives and accurately machined, axially symmetrical inserts[2], jets of ultrafast particles are extruded from these inserts, which follow each other accurately on a straight line trajectory.

It was observed from the start[4] that the trajectories of solid particle jets in a normal atmosphere are not uniformly bright but appear to consist of irregular pulses of light interrupted by short non-luminous parts. It was found that each individual ultrafast particle brightens and darkens intermittently. On being projected into the atmosphere the artificial meteors first heat up and then melt or evaporate superficially, processes which cause them to cool down.

This sequence of events, which often repeats itself many times, was first recorded with a simple but effective device, *a camera or a telescope in motion* [3] [5]. In the case of artificial meteors ejected from metal-lined shaped charges, results obtained with a camera rotating around an axis parallel to the jet of meteors proved most revealing—as evidenced by the photographs on these pages. Other investigators are using rapidly moved films, but this method seems to me more difficult than rotating the camera.

It is seen from the diagram below (right) that two groups of particles are ejected. Those in the first group have velocities in the range from 5 to 10 km/sec. Group two mainly consists of a large slug with a velocity of about 2 to 3 km/sec. The range of the fastest particles, depending on their nature, may be of the order of 100 meters in air at sea level.

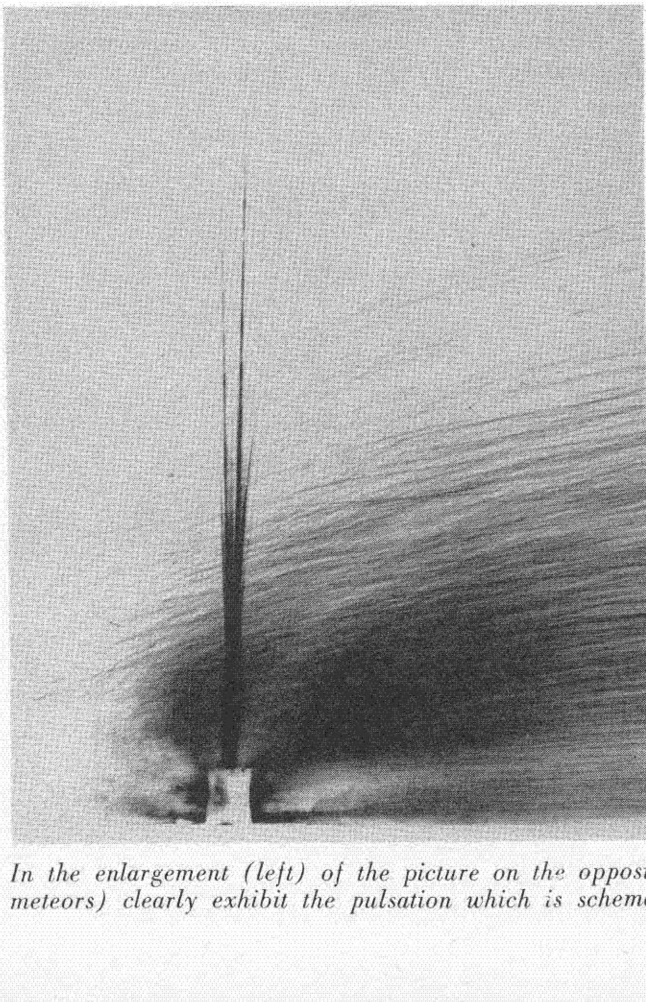
During the bright flashes, material is sprayed from these particles into the surrounding atmosphere, as shown in the diagram. Spectra of these flashes contain the emission lines of the elements which constitute the liners, as well as of their oxides[6]. There may be one flash, or groups of two and more flashes repeating themselves regularly, as shown schematically for the tracks a, b and c in the diagram. This presumably means that, in addition to periodic flashes, spinning of irregularly shaped particles contributes to the varying light intensity along the trajectory.

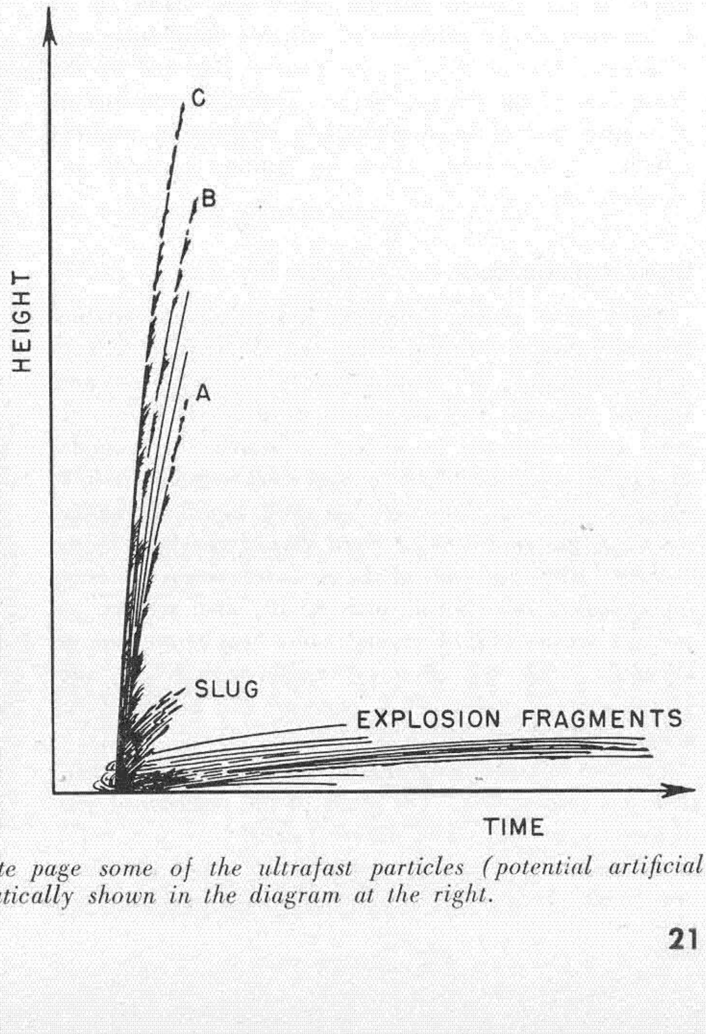
A few years ago Dr. A. G. Wilson and the author, working with the Palomar Schmidt telescopes, also discovered the rather frequent occurrence of natural *regularly pulsating meteors*[3] [4].

Recently some investigators[7] have succeeded in propelling individual ultrafast pellets whose masses were of the order of a fraction of a gram to several grams, and whose drag characteristics, spectra and color temperatures could be determined. The latter were found to be of the order of 2900°K for Al pellets moving through air with 5 to 6 km/sec.

Upper atmosphere and interplanetary space

In 1946 a program[8] for the launching of artificial meteors from high flying rockets was initiated, which was at first privately financed. With the cooperation of US Army Ordnance, the first night firing of a V-2 rocket took place on December 16, 1946. Six shaped changes were installed in this rocket. Unfortunately the firing mechanism failed at the crucial moment. No further attempts have been made since then to launch artificial meteors[9] from great heights for the purpose of projecting them into interplanetary space, because neither the necessary funds could be raised nor were firing facilities readily available.





In the enlargement (left) of the picture on the opposite page some of the ultrafast particles (potential artificial meteors) clearly exhibit the pulsation which is schematically shown in the diagram at the right.

In particular, three objections were raised against any further experimentation with artificial meteors[9]. These objections are: 1) Artificial meteors are too slow and too small to be seen in the tenuous upper parts of the atmosphere since they cannot be expected to heat up enough. 2) They are also too slow to leave the earth or even to reach great heights. 3) It was feared that the launching of artificial meteors within the United States might conceivably endanger people because of falling fragments.

The great progress which has been made toward the elimination of objections 1 and 2 will be described below. As far as objection 3 is concerned, artificial meteors could be fired at sea, on the extended Australian rocket range, or in the Sahara desert, if this type of experimentation is not desirable in this country. For this purpose I have already established successful contacts in Australia and in France.

Intensification of brightness

For a particle of given size and speed the brightness can be increased in two ways. First, one may choose particles (Tracers) which, when heated by the initial extrusion process, will *react* vigorously with the oxygen or with the nitrogen of the air. Secondly, when air is completely absent this method will not work; but one may heat the meteors through the initiation of *internal solid-solid chemical reactions* in order to make them visible.

This can easily be accomplished through the choice of liners in the shaped charges which are made up of highly compressed mixtures of suitable solid fuels and oxidizers. The reaction in the liner is initiated by the detonation of the shaped charge. Thermit, composed of aluminum and of iron oxide, is a well-known reactive mixture of this kind, which on ignition becomes extremely hot.

Chemical heaters

Much more potent "chemical heaters" are available, however, even if we do not tap the resources of "Fragment Chemistry" or "Metachemistry"[10]. For instance, suitable elements may be mixed stoichiometrically with solid oxidizers such as $KClO_4$, or similar compounds. Through the choice of the proper fuel component it is possible to produce intensely hot solid, liquid or gaseous jets from the explosion of lined shaped charges. Using elements at the two ends of the periodic system one may, for instance, mix Boron with $KClO_4$ and achieve an average density of 2.51 gr/cm^3 and a heat of reaction of about 12 $Kcal/cm^3$; or mix tungsten with $KClO_4$ and get an average density of 5.7 gr/cm^3 and a heat of reaction of 3.8 $Kcal/cm^3$.

The two mixtures will produce gaseous and solid particle jets respectively. The study of the reaction of jets of these types with air of different density, or with solid and liquid media, promises to open up some interesting new fields. In particular, it is to be foreseen that because of internal chemical heating the drag of projectiles through different media may, interestingly enough, be both decreased or increased.

Particles which are internally heated during their flight produce luminous trajectories even when flying in high vacuum outside of the earth's atmosphere. Through the ejection from shaped charges of suitably chosen materials one also has the means to experiment reactively with the various constituents of the upper atmosphere[10].

Increase of speed

With commercially available shaped charges and liners one may eject fast solid particles whose speeds seldom surpass 10 km/sec. The velocity of escape from the earth at the poles is 11.2 km/sec. Obviously, in attempting to project small slugs into interplanetary space one would prefer to have some extra speed available.

There are two general possibilities to speed up the jets from lined shaped charges:

1) Higher speed of the ejected particles can be achieved with conventional explosives and proper liners if one improves on their design and the method of initiating the detonation. With this approach velocities as high as 90 km/sec have now been achieved with beryllium liners[11]. 2) In the not-too-far future, conventional chemicals in shaped charges will no doubt be replaced by much more potent explosives which liberate more energy, at detonation velocities superior to those which can now be achieved. These unconventional explosives will be made up of *fragments* or *radicals* of chemical molecules or of *metastable* states of such molecules. The stabilization of macroscopic density of such fragments and metastable molecules is the task of two new branches of chemistry for which I have proposed the designations Fragment Chemistry and Metachemistry[10]. Work in these fields was initiated only a short time ago, but important results may be forthcoming shortly.

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