them[6]. It is possible, therefore, that type III bursts are caused by cosmic rays of solar origin. However, it should be remarked that unless the particles are much heavier than protons, their energies at velocities of the order of 5×10^4 km./sec. must be considerably lower than those deduced by cosmic-ray investigators. Nevertheless, the 'low' velocities seem to offer the only simple explanation of the long time delays.

Compound Bursts

We now know that two kinds of activity may occur at the time of solar flares : the type II out-bursts and the type III clusters. During the year, we have recorded four of the former and ten of the latter. Either kind may occur without the other, but on three occasions we have observed the com-bination of the two. On each occasion the type II burst followed the type III cluster after a time delay of several minutes.

An example is shown in Fig. 3, plotted in terms of heights in the solar atmosphere. The calculated velocities are 230 km./sec. for the type II burst and $1 \cdot 0 \times 10^5$ km./sec for the type III. Both the velocity and the time delay of the type II differ considerably for the three cases observed. Yet in each case extension of the velocity lines towards the origin yields a point of intersection in the lower corona within 10^5 km. of the photosphere. This suggests that the two portions of the compound burst are associated with disturbances, perhaps streams of matter, ejected simultaneously from a common source located low in the solar atmosphere. Such an 'explosion' may well be the primary cause of the flare.

Speculation on the physical nature of this phen-omenon has led us to consider several possible mechanisms.

(1) An explosion involving thermo-nuclear or chain reactions between nuclei of light elements, the products being emitted with characteristic velocities. Such explosions do not seem feasible at the low densities believed to exist in the solar atmosphere, but it is not known whether they may occur slightly below the photosphere.

(2) A sudden accelerating process involving large-scale electric and magnetic fields. The two velocities could result from the acceleration of charged par-ticles of very different mass in the same field. How-ever, the large velocity ratio may be difficult to explain.

(3) A disturbance of some kind which gives rise to the combination of a fast corpuscular ejection and a shock wave. It is noteworthy that the typical slow (type II) velocity is of the order of the mean speed of thermal protons in the corona, which may be identified with the velocity of sound.

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SOME PHYSICAL PROPERTIES OF METALLIC PLUTONIUM

FOLLOWING a recent declassification decision, it is now permissible to disclose some of the properties of metallic plutonium (Pu, $Z = 94$).

Between room temperature and its melting point, pure plutonium was found to exist in five allotropic modifications, labelled α, β, γ, δ, ε. The temperatures at which the phase changes occur are given in Table 1, determined by dilatometry at heating- and cooling-rates of about $1\frac{1}{2}$ deg. C. per min.

Table 1. TRANSITION TEMPERATURES (°C.)

	Heating	Cooling
$\alpha \rightleftharpoons \beta$	136	85
$\beta \rightleftharpoons \gamma$	225	About 160
$\gamma \rightleftharpoons \delta$	320	,, 250
$\delta \rightleftharpoons \varepsilon$	480	480

During cooling, the $\varepsilon \rightleftharpoons \delta$ change occurs with little or no temperature hysteresis; but the remaining transformations show considerable sluggishness, which makes it difficult to quote temperatures for the start of the $\delta \rightarrow \gamma$ and $\gamma \rightarrow \beta$ changes. The $\beta \rightarrow \alpha$ trans-formation commences sharply at 85° C., and con-tinues slowly at room temperature.

The density of α-plutonium at room temperature has been determined by the measurement and weighing of pressed geometrical shapes, and by displacement. The approximate densities of the other phases have been found from dilatometer measurements. Typical figures are given in Table 2 : the values for the β, γ, δ and ε phases refer to the low-temperature end of the stable range of the phase.

Table 2. DENSITIES OF PHASES OF PLUTONIUM (gm./c.c)

α	β	γ	δ	ε
19·0	17·4	16·6	15·4	16·4

Features of interest in this table are the consider-able increase in density on passing from the δ- to the ε-phase, and the large difference in density between the densest (α) and the least dense (δ) phase.

Table 3 gives values for the coefficients of thermal expansion of the various phases. In the α-, β- and δ-phases the coefficients vary considerably with the temperature, but in the γ- and ε-phases the expan-sions are almost linear. The values given are taken at the middle of the appropriate temperature-range.

Table 3. COEFFICIENTS OF LINEAR THERMAL EXPANSION (parts in 10^6/°C.)

α (below 70° C.)	α (above 70° C.)	β (below 190° C.)	β (above 190° C.)	γ	δ	ε
40	65	32	54	48	−33	20

A most interesting feature is the negative tem-perature coefficient of expansion shown by δ-pluto-nium. This behaviour is perhaps unique in a poly-crystalline pure metal. At the low-temperature end of the stability range of the δ-phase, the coefficient of expansion is very small and becomes negative at high temperatures, getting numerically greater as the temperature increases to the $\delta \rightarrow \varepsilon$ change point at 480° C.

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CONCURRENTLY with the above work, a more extensive programme of research was carried out at the Atomic Energy Research Establishment, Harwell. The transition temperatures between the five allotropic modifications of plutonium have been determined by several methods, the results being summarized in Table 4. The temperatures quoted are approximate typical values, given to the nearest multiple of five degrees : extensive experiments show considerable variations from specimen to specimen. In most cases actual experimental values are within a range of ± 5° C.; but isolated results have been obtained well outside this range.

The electrical resistance and the coefficients of electrical resistance and thermal expansion on heating are given in Table 5. Behaviour on cooling is complicated by severe hysteresis effects and sluggish transformations, so that to quote simple values without extensive qualification would be misleading. Values for cooling are therefore omitted.

The density of α-plutonium has been determined by the displacement method, and values for the other phases have been calculated from the dilatation curves on heating. Variations in the density have been observed from specimen to specimen. The value quoted is for a specimen after standing for several months at room temperature. A typical value for specimens immediately after dilatation runs is about 18·7 gm./c.c., the low figure being presumably due to the retention of other phases. The values given for the β- γ-, δ-, ϵ-phases are typical for these phases at the lower end of their stable range (Table 6).

Table 6

Phase	Density (gm./c.c.)
α	19·25
β	17·3
γ	16·7
δ	15·7
ϵ	16·3

Full discussion of the theoretical implications will become possible only when security limitations permit the disclosure of some other properties of plutonium ; but in addition to the negative coefficient of thermal expansion of the δ-phase, and the large density difference between the latter and the α-phase, the following points may be noted :

(a) The relatively high values of electrical resistivity and the negative and extremely low temperature coefficients of resistance of some of the phases.

(b) The large hysteresis associated with the $\delta \rightarrow \gamma$, $\gamma \rightarrow \beta$ and $\beta \rightarrow \alpha$ phase-changes, and the complete absence of hysteresis in the onset of the δ-phase change which, however, proceeds only partly to completion, even with long soaking periods.

(c) The large variations in properties between one specimen and another, which it is difficult to account

Table 4

Phase	Transition temperatures (°C.)					
	Thermal analysis*		Dilatometry†		Electrical resistance*	
	Heating	Cooling	Heating	Cooling	Heating	Cooling
$\alpha \rightleftharpoons \beta$	140	80	135	80§	135	90§
$\beta \rightleftharpoons \gamma$	235	145‡	225	Transformation obscured on all specimens due to sluggishness	220	160‡
$\gamma \rightleftharpoons \delta$	325	245‡	315		325	225‡
$\delta \rightleftharpoons \epsilon$	475	475	480	480‖	480	480‖
Melting and freezing points	640	640				

* Rates of heating and cooling, approximately 2 deg. C. per min.
† Rates of heating and cooling, approximately 1 deg. C. per min.
‡ Ill-defined transitions on some specimens ; arrests obscured on others.
§ Start of transition : transformation occurs progressively to room temperatures, and sometimes continues isothermally.
‖ On cooling, the change does not appear to go to completion: the density decreases only from 16·3 to about 16·1.

Table 5

Phase	Resistivity* (micro ohm cm.)	Coefficient of electrical resistance on heating per deg. C. ($\times 10^{-5}$)	Linear coefficient of thermal expansion on heating per deg. C. ($\times 10^{-6}$)
α	150	− 20 to − 40†	+ 50 to 65†
β	116	− 10	+ 43
γ	115	− 4 to − 20‡	+ 39
δ	111	+ 7	− 27§
ϵ	123	—	+ 20‖

* Mean figures for several specimens ; they refer to the low-temperature end of each range. The variation from specimen to specimen is about ± 3 micro ohm cm. The values for β-, γ-, δ- and ϵ- have been corrected for volume changes on the basis of isotropic expansions from the α-phase.
† The curve is not linear ; these are limiting values for several specimens.
‡ These are limits for several specimens ; one specimen gave a value of + 20 × 10⁻⁵.
§ The curve is not linear over the whole range ; this is a typical value for the linear portion of the curve.
‖ Typical value for several specimens ; variations from approximately 5 to 30 × 10⁻⁶ have been observed on some specimens.

for by the presence of impurities if normal experience is taken as a basis for comparison.

Many features of the behaviour of plutonium have been necessarily omitted from this short summary ; but it is hoped to publish a more detailed account of the experimental results elsewhere.

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