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Progress Report

November 1967 - June 1968

GROWTH OF BURNING TO DETONATION
IN LIQUIDS AND SOLIDS

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(a) Summary of Work

An investigation is being made of deflagration and growth to detonation in liquids and solids with special reference to the role of small discontinuities in promoting sensitivity, and the Deflagration, Detonation Transition.

As with previous reports it will be seen that the approach has been on a fairly broad front covering a range of experimental studies. The results are best discussed under separate headings. Much of the work reported is a continuation of established lines of approach.

(i) Liquid explosives

Previous workers in this laboratory have studied the initiation and growth of explosion in thin films of nitroglycerin (Bowden & McOnie 1967). They confined the explosive between sheets of glass and perspex, and initiated it by rapidly discharging a capacitor between the electrodes of a spark gap located in a small reservoir in the centre of the film. The transition from burning to detonation of the explosive was found to be strongly dependent on an annular zone of cavitated liquid within the film and it was suggested that this was produced by precursor waves in the confining solids.

In an effort to understand the mechanism producing such a cavitated region work has been started to investigate the cavitation phenomenon in inert liquid films having similar confinement to the nitroglycerin films described above. Two types of experiment are in progress both utilising the C4 continuous access High Speed Camera:

(1) Water films of various thickness have been used with a given perspex confinement and it appears that the velocity of the cavitation head is dependent on the water film thickness.

(2) The thickness of the confining perspex has been varied for a water film of given thickness. It is found that the cavitation becomes much less intense as the thickness of the confinement is increased, but the velocity

of the cavitation head does not seem to depend on the thickness of the confinement.

It seems that the cavitation phenomena is more complicated than was at first thought with perhaps two or more mechanisms involved.

F. P. Bowden, F.R.S. and M. P. McOnie, 1967, Proc. Roy. Soc. A298, 38-50.

(ii) Cavity collapse

The importance of the fracture and collapse of cavities on the transition to detonation has been established in earlier work. Detailed studies of the collapse of cavities by shock are at present in progress using the Beckman & Whitley (Model 189) camera. It appears that cavities not only collapse (with adiabatic heating of the gas inside) but under some circumstances involute, forming a high-speed jet. This jet may reach several hundreds of meters/sec. At a later stage when the shock has passed the cavity 'rebounds' and this sends a strong shock into the liquid. The importance of all these factors on the explosion process is being examined. In one experimental configuration a single crystal of explosive is immersed in a liquid and a cavity is formed adjacent to it, this cavity is then collapsed by a shock from a detonator.

(iii) Azide decomposition

A detailed study of the kinetics of the slow thermal decomposition in the series of azides Na^+ , Tl^+ , and Pb^{++} has now been completed. In these experiments, measurements were made on individual single crystals of each material thus eliminating the complications in interpretation introduced in conventional studies of crystalline compacts, by such factors as ill defined size distributions and packing factors. The main conclusions to be drawn from this study may be summarised as follows:

- (i) The rate of decomposition is in all cases directly proportional to the area of reacting surface. This conclusion is substantiated over a very wide temperature range, e. g. , $100^{\circ} - 450^{\circ}\text{C}$ for lead azide.
- (ii) Decomposition proceeds along specific crystallographic planes and examination of partially decomposed material in the scanning electron microscope suggests that nucleation of the metal produced in the reaction does not play an important part in the kinetics of the decomposition.
- (iii) The rate curves are in most cases linear over a wide range of percentage decomposition (usually $> 50\%$) and induction periods are not observed except at low temperatures in sodium and thallium azides.
- (iv) These induction periods seem to be associated with the evolution of impurity species from the crystal in such a way that the main part of the reaction does not start until 'reaction centres' have been formed*.

Experiments are under way which are aimed at correlating the surface decomposition of the azides with their detonation characteristics. The role of reaction centres in the decomposition process is also being investigated.

* 'The use of a quadrupole mass filter in the study of a reacting surface', P. G. Fox and R. F. Walker, Symposium on Mass Spectrometry, p. 153, Butterworths, London, 1968.

(iv) Initiation of fast decomposition in explosive crystals

Experiments are being done to study the initiation of propagation of fast decomposition in single crystals of metallic azides (Pb and Ag). Different methods of initiating the crystals have been used. These are:-

- (i) By bringing a single crystal into a furnace heated to a fixed temperature and then studying the ensuing behaviour under an optical microscope.
- (ii) By exploding bridge wires.
- (iii) By shocks.
- (iv) By ruby laser powerful pulses of radiation.

A Beckman and Whitley camera (model 189) has been used to study the propagation of fast reactions. Pictures of detonating crystals of PbN_6 have been taken. Detonation velocities up to 3 Km/sec have been measured.

A method has been developed by which controlled size crystals of β and α lead azides are grown in the same vessel. Examples of crystals are given in figures 1 and 2. Experiments to compare the sensitivity to shock of PbN_6 and Ag N_3 are also being performed.

The conclusions are:

1. The initiation of single crystals of PbN_6 is a surface phenomenon.
2. The velocity of propagation of reaction in single crystals of Pb and Ag azides is dependent on their dimensions.

(v) Fracture of inert crystals.

There is a programme of work in the laboratory for the study of fracture processes. Some of this work is applicable to the role of initiation in explosives in that it helps in the understanding of: (a) the fragmentation process which frequently precedes detonation in crystals of explosives,

particularly the secondaries, (b) the importance of defects on both the initiation and propagation stages of fracture.

The work has shown that fractures can reach several thousands of meters per second in many solids. Since the energy associated with the tip of a fast moving crack is considerable it seems possible that chemical decomposition could occur. This point is now being investigated by fracturing solids under vacuum and detecting any gases given off by mass-spectroscopy.

(b) Difficulties Encountered

No major difficulties have been encountered in the period covered by this report.

(c) Research Plans

Much of the proposed work has been indicated in part (a) of this report. New studies will include (i) liquids - cavitation, cavity collapse, jetting and importance of initiation and deflagration, detonation transition. (ii) Solids; role played by fracture in starting and stopping explosion; fast reactions started by ultra violet light, laser light, hot wires, micro-particle impact; measurement of hot-spot sizes; measurement of critical explosion temperatures; studies of defects in explosives using transmission electron microscopy at low beam densities, and X-ray microscopy.

(d) Inventions

No inventions have been made during the period of the grant.

(e) Personnel

The work performed under this grant has been supervised by Professor Bowden, Dr. Yoffe and Dr. Field.

Dr. Fox is studying the decomposition of the azides using the

scanning electron microscope and the mass spectrometer. Dr. Chaudhri is currently studying the initiation of fast decomposition in explosive crystals and, with Dr. Bastow, is developing the micro-particle accelerator.

(f) Conferences, Travel

Professor Bowden is on the organising committee and will attend the Twelfth International Symposium on Combustion to be held in Poitiers, France, July 14-20 1968. Dr. P. G. Fox and Dr. M. M. Chaudhri will also attend this Conference.

Dr. P. G. Fox will participate in the 4th AFOSR Combined Contractors' Meeting on 'Combustion Dynamics' in Madrid, Spain, July 8-12, 1968. He will present a paper on some recent work under this contract.

FIGURE CAPTIONS

Figure 1.

Large single crystals of α -lead azide showing a high level of perfection.

Magnification x21.

Figure 2.

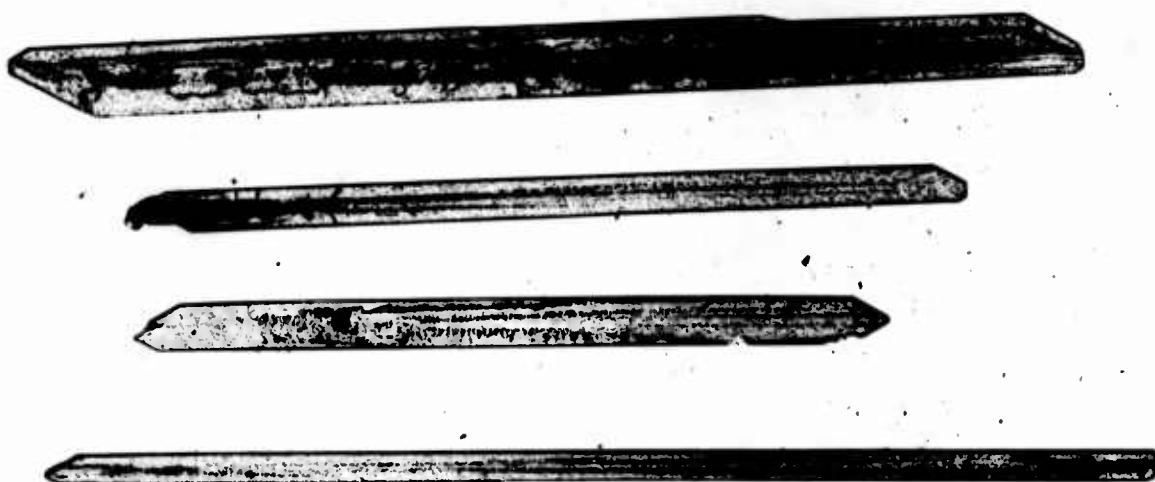
Large single crystals of β -lead azide showing a high level of perfection.

Magnification x 14.

Fig. 1



Fig. 2



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13. ABSTRACT A high-speed photographic study has been made of the initiation of explosion in liquids and single crystals of explosive solids. The physical homogeneity of the material has been shown to have a marked effect on sensitivity. An extension has been made to thermal explosion theory. ()			

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KEY WORDS

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