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THE INVESTIGATION OF BOMBS AND EXPLOSIONS

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The scientific advances which man has made during the past few centuries have included a widespread use of materials which we commonly classify as explosives. In fact, a survey of their varied use indicates the extent to which our technical development depends upon the violent energy changes which these substances place at our disposal. Ordinarily the word *explosive* carries with it an unpleasant connotation of destructive forces inimical to human welfare. The facts are somewhat at variance with this idea. All mining operations, for metallic ores, for coal or oil, all quarrying, much of the railroad and highway construction, particularly in mountainous regions, depend upon the proper use of explosives. The construction of canals, tunnels, dams and aqueducts require their use in large quantities. Agriculturalists employ them for clearing land of large boulders and stumps and also for constructing drainage ditches. In a more limited sense, all of our internal combustion motors, automobiles, airplane and Diesel engines, are energized by the controlled combustion of explosive gaseous or vapor mixtures. The explosives used for military or sporting purposes

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and for pyrotechnics and signaling, except in time of war, represent a very small fraction of the world's total explosive production.

With such widespread use of explosives it is not surprising to find the lawless element of society utilizing these forces of concentrated energy for criminal purposes such as theft, destruction of property, intimidation and sabotage. To attempt to prevent this illegal usage by rigidly regulating the sale, storage and handling of legitimate explosive supplies would be practically impossible without placing an unreasonable restraint upon industry and agriculture. Legislation, regulating the transportation, storage, and use of explosives, insuring, so far as possible their delivery to legitimate users, cannot wholly stop the supply to criminals. Storage magazines may be broken into, a dozen sticks of dynamite sufficient to manufacture several bombs may be stolen from some farmer who has purchased the explosive for the blasting of stumps, or custodians of legitimate explosive stores may be bribed to deliver a small quantity with no questions asked. It is quite possible, furthermore, for a person of moderate skill to prepare, in his own home, sufficient supplies of explosive substances to do considerable damage.

Statutes Concerning Explosives

The laws of the different states vary widely in regulating explosives and their use. In most states the manufacture, transportation and sale of explosives is subject to state control. This involves the location, construction, and licensing of the manufactory, and the proper labeling of explosives for shipment. Transportation with passengers on common carriers is usually forbidden, storage is supervised as to location, size and structure of the magazines, sales are required to be recorded, and use in mines and quarries is subject to definite safety regulations. Ordinarily small amounts of explosives such as a few pounds of shotgun powder, fireworks, small-arms and sporting ammunition, and fuel for internal combustion motors are exempted from such restrictions. Some states have forbidden the sale or use of fireworks within their jurisdictions.

Although not always specifically mentioned, the intentional use of explosives for homicidal purposes is generally classified as murder. Likewise the wilful destruction of property by means of explosives is usually classified as a felony where the locality blown up is ordinarily inhabited or occupied by human beings. The placing of an explosive in a building, ship, automobile or other property where the explosive remains unexploded is also frequently the subject of legislation. The use of explosives for burglary is specifically prohibited by the statutes of many states.

The possession of explosives in most states is not a serious offense unless intent to use them illegally can be proved. In one state (Kansas) even where criminal intent can be shown, the offense is only a misdemeanor. In others, the mere possession of an explosive by a person who cannot give a satisfactory explanation for a legal use, is taken as *prima facie* evidence of illegal intent.

Some idea of the extent of this difference in the statutes of the various states may be had by comparing the laws of a state such as Alabama with those of California. In Alabama the only specific statutory regulation against bombing is in connection with property damage. A conviction for bombing property is a felony punishable by a fine of one hundred to five hundred dollars and/or one to five years' imprisonment. In California, even the *possession* of explosives by persons other than those who are "regularly engaged in the manufacture, sale, transportation or legitimate use in blasting operations, or in the arts" is guilty (*prima facie*) of reckless and malicious possession which is punishable by a fine of not more than five thousand dollars and/or imprisonment for not more than five years. Inasmuch as "explosives" are designated as "every explosive substance having an explosive power equal to or greater than black blasting powder (not including small arms ammunition)," this law is very drastic. Under its terms, a person carrying a large firecracker on the street might technically be considered as guilty of "reckless and malicious possession."[1] In California the possession of tear gas cartridges or bombs is also illegal.

There seems to be a progressive recognition of stench bombs and tear gas as subjects for legislative control. This has been particularly true in recent years since their use in industrial warfare and sabotage has become common.

Definitions

While there may be little doubt in our minds as to just what is meant by such terms as "bomb," "explosive" or "explosion" one might find it difficult, offhand, to propound an adequate definition of these common terms.

"Explosion" is defined as "the act of exploding; a rapid combustion, decomposition or similar process resulting in a great and sudden development of gases, and consequent violent increase of

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[1] The Missouri law is equally vague and inclusive in defining the term "bomb."

pressure, usually causing a loud report."[2] A second meaning is, "a sudden breaking apart, shattering or bursting in pieces by internal pressure, as that of gas or steam." The latter are ordinarily known as pressure explosions and will not be dealt with in this paper.

"Explosive" is any substance that may cause an explosion by its sudden combustion or decomposition.[3]

"Detonation" is a "violent explosion; one resulting from the practically instantaneous decomposition or combustion of unstable compounds such as nitroglycerine, trinitro-toluene, or mercury fulminate, as distinguished from explosions of black powder."[4]

"Bomb" is poorly defined as "a hollow projectile of iron generally spherical, containing an explosive material which is fired by concussion or by a time-fuse; also any similar receptacle of any shape containing an explosive; as, a *dynamite* bomb."[5] The spherical hollow iron projectile is archaic and appears nowadays chiefly in cartoons. Modern bombs are no longer constructed on such a pattern.

Classifications of Explosives

Although all explosive reactions are characterized by a rapid liberation of energy[6] (usually manifested by the liberation of a comparatively large volume of gaseous products and the production of much heat),[7] the velocity of this change varies over a wide range. Explosive gases such as gasoline-air mixtures, when ignited by a spark, produce an explosive wave which travels at comparatively low velocity of about 30 feet per second. When low-strength dynamite is properly detonated, the velocity mounts to 10,000 feet per second, while in violent shattering *brisant* explosives such as trinitrotoluene (TNT) and nitroglycerine, their detonation attains a speed of about 25,000 feet per second. On the basis of the speed of their explosive reaction, we roughly classify explosives into two categories: *low* explosives and *high* explosives.

Low explosives are those having explosion velocities of a few

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[2] New Standard Dictionary (Funk and Wagnalls Co., 1929).

[3] *Supra*, note 2.

[4] Webster's New International Dictionary (2d ed., 1935).

[5] *Supra*, note 2.

[6] The actual quantity of energy liberated per unit weight of explosive is usually small. Thus, nitroglycerine yields only 2850 B. T. U. per pound, whereas ordinary coal produces 13000 B. T. U. per pound. The difference in energy intensity is due to the fact that coal burns slowly, whereas nitroglycerine detonates at the rate of 4 miles per second.

[7] Calculated temperatures reached momentarily during the explosion of solids vary from about 2000° C. in the case of ammonium nitrate to 3540° C. for blasting gelatine.

thousand feet per second or less. These constitute the combustible gases such as hydrocarbons (including gasoline), carbon monoxide, hydrogen, and carbon disulphide (each mixed with sufficient air or oxygen to furnish an explosive mixture) and also such propellants as black gunpowder or smokeless powder, in which the oxygen necessary for combustion is furnished by the nitrate portion of the explosive itself. Members of this group are characterized by a comparatively slow "push" type of explosive effect which may be utilized by pushing the pistons of internal combustion motors or by breaking off large pieces of rock or coal (with a minimum of pulverizing effect) in quarrying and mining. The sound of such an explosion is of low frequency and varies from a "puff" or "pop" to a "boom." There is little or no evidence of violent localized damage in the immediate vicinity of the explosive—but rather a generalized effect of a "push" noted throughout the locality.

It is the slowness of the explosive reaction which renders the members of this group particularly valuable in their industrial application. A high explosive would shatter a motor cylinder instead of pushing the piston down at a comparatively slow rate. TNT would reduce coal or building stone to an unsalable powder if it were used in mining or quarrying, and a cartridge loaded with high explosive would burst the gun barrel instead of driving the bullet out of the muzzle. Low explosives are ignited by a spark or flame.

High explosives, having explosion velocities of 5000 to 25,000 feet per second, on the other hand, have quite the opposite effect. The violence of their detonation produces an extreme shattering effect in the immediate vicinity of the explosive. The violence of this shattering effect (*brisance*) decreases sharply with increasing distance from the explosive. Thus a bomb composed of several sticks of 60% dynamite exploded in the center of the floor of a large room would shatter the floor in the immediate vicinity of the bomb but would do comparatively little damage to the remote parts of the room—except for the breaking of window panes and destruction wrought by flying debris. The sound of the explosion of a high explosive is of higher pitch and shorter duration than that of a low explosive. It may best be characterized as a sharp "crack." It should be borne in mind that most of the so-called "high explosives" may not be exploded directly by a spark but require a violent shock such as the detonation of a blasting cap in order to initiate their explosion. High explosives such as picric acid or dynamite, if lighted by a match will burn with more or less violence, but ordinarily will not explode. However, if the burning is active enough to raise the temperature of the adjacent unburned explosive to about 175° to 250° C., this heating may produce a detonation. In general, heating increases the sensitiveness of high explosives to physical shock. High explosives also contain sufficient oxygen within their molecular structure to provide for the extremely rapid combustion which occurs when they are detonated; they do not require the presence of atmospheric oxygen for their explosion.

On the basis of the difference of explosion velocities of "high" and "low" explosives, the differences in their effects are rather obvious—the low explosive produces a dull "boom" and a generalized "push" type of damage, while the "high" explosive detonates with a sharp "crack" and produces a violent shattering type of damage localized at the site of the explosive, with the intensity of disruptive or shattering damage diminishing rapidly with the distance from this point. This oftentimes enables one to state with a high degree of certainty the general class of explosive responsible for the damage in a particular case—even though there is no trace of explosive, container, fuse, or ignition mechanism to be found on the premises. These two classes of explosive damage may be illustrated by the photographs in Figures 1 and 2.

FIGURE 1
Result of an explosion of gasoline vapor, showing "push" effect of a *low* explosive.

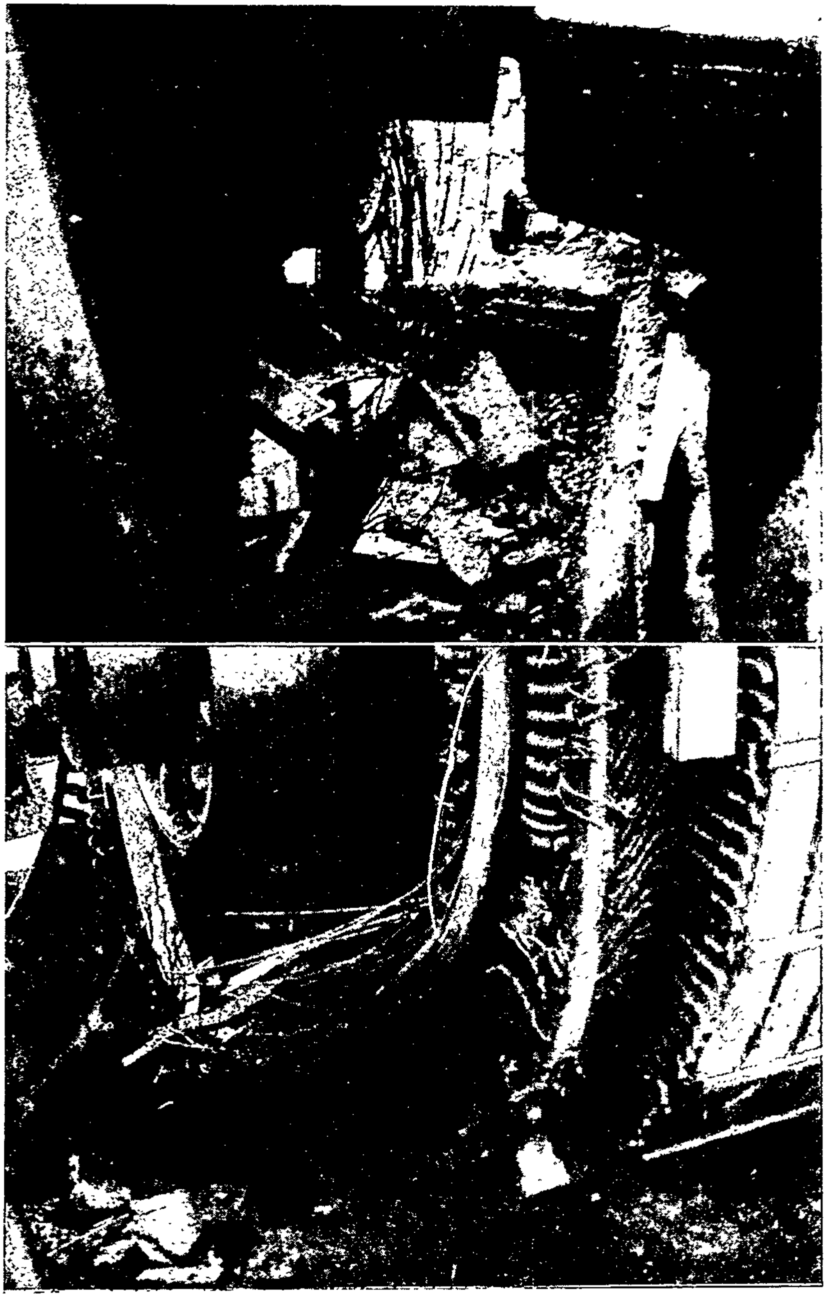

FIGURE 2
Shattering effect of a high explosive (dynamite) set off at the base of a large motor-generator. Note pulverized condition of the concrete in the foundation pit (upper photograph) and localized rending damage to wrap wires (lower photograph).

Explosive Gas or Dust Mixtures

Combustion of any inflammable material requires two essential factors: (1) adequate oxygen supply to support the combustion, and (2) sufficient heat to raise the temperature of the combustible mixture above the ignition point of that combustible substance. Adequate oxygen supply may be provided by gaseous oxygen (usually air) in sufficient quantity, or by means of chemical compounds which contain oxygen in available form (such as nitrates or chlorates). If the oxygen supply is too meagre, combustion cannot be initiated regardless of the amount of heat applied; likewise if combustion has started, any shutting down of the oxygen supply below the amount necessary to support combustion will result in a smothering of the fire.

The ignition temperature of a combustible substance is the temperature to which it must be heated before burning will take place. This varies for different substances, ranging from 105° C. (221° F.) for carbon disulphide, up to 400° C. (752° F.) or more for cylinder oil. Usually if there is an adequate supply of oxygen, simply bringing a portion of the combustible material up to the ignition temperature is sufficient to produce a fire or explosion; the heat of the combustion will furnish sufficient heat energy to maintain the temperature above the ignition temperature. If, for any reason, the temperature of the burning mass is decreased to a point below the ignition temperature of the combustible substance, the burning will die out.

In combustible or explosive mixtures of gas (such as natural gas, illuminating gas or gasoline vapor) and air, we find that in order for an explosion to take place (1) the air and combustible gas must be present in the proper proportions, and (2) this combustible mixture must be raised, in part, at least, above the ignition temperature by means of a spark, flame or other source of heat. If the combustible gas is not present in sufficient concentration, the meagre amount of heat produced by its burning will not be sufficient to heat the adjoining portions of the gas mixture above the ignition temperature and the flame will not propagate through the mixture. However, if the percentage of combustible gas be slowly increased, we eventually find a mixture in which the heat of burning the gas is sufficient to raise the adjoining portions above the ignition temperature. When a spark is applied to such a mixture, a feeble "pop" or explosion will take place. As the concentration of the combustible gas is increased further, the mixture becomes more violently exlosive until an optimum concentration is reached (usually near the point where the combustible gas and air are present in the exact proportions for perfect combustion) (Fig. 3.).

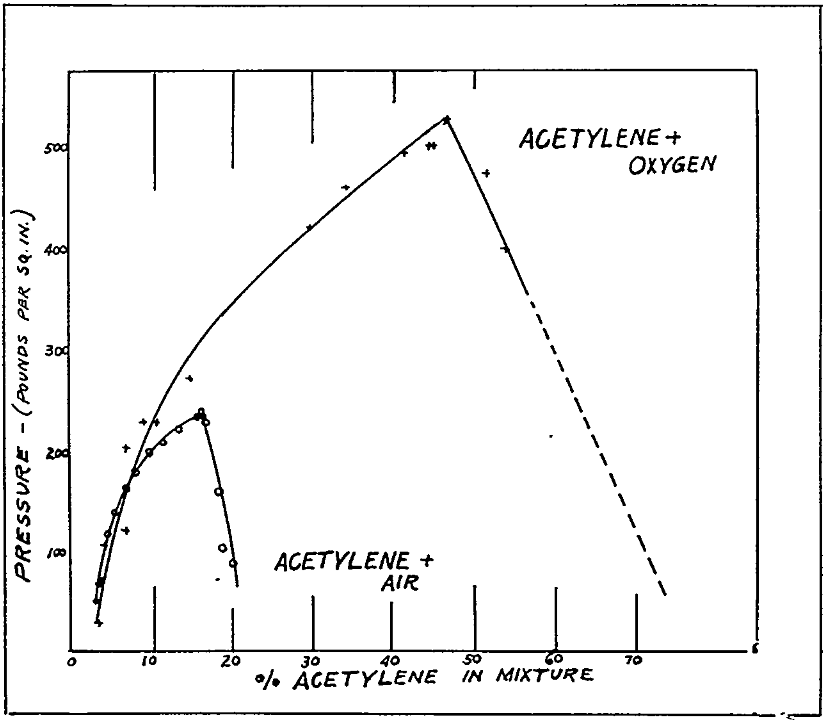

FIGURE 3
Pressure effect of explosions of mixtures of acetylene with air and oxygen. (Courtesy of Underwriters' Laboratory, Chicago.)

Increasing the percentage of combustible gas above this amount *decreases* the violence of the explosion. This is due to the fact that the combustible gas is in excess of the oxygen available for its combustion and this unburned excess acts as an inert heat-absorbing blanket which diminishes the pressure development. Finally, as the percentage of combustible gas is further increased, the mixture becomes non-explosive due to inadequate oxygen supply.

For any gas mixture with air or with oxygen we have a *range* of explosibility. Any mixture within this range will explode more or less violently if, by means of a spark or flame, a portion of it is brought up to its ignition temperature. If this composition of the mixture is near either the upper or lower limit of explosibility, the explosion will be very feeble (Fig. 3). The explosive range of gas-air mixtures varies with different gases. A few of the more important ones are given in the following table:

Gas or Vapor	*Percentage of Gas Mixed with Air to Give:*[8]	
	Lower Limit of Explosibility	Upper Limit of Explosibility
Hydrogen	4.1%	74%
Acetylene	2.5	35 to 83*
Carbon Monoxide	12.5	74.0
Ethylene	2.75	28.6
Methane	5.3	14.0
Ethane	3.2	10.6
Propane	2.4	9.5
Ammonia (Dry)	16.0	27.0
Gasoline	1.4	6.0
Benzol	1.4	8.0
Toluol	1.3	7.0
Ether (ethyl)	1.85	36.5
Acetone	2.5	13.0

The presence of inert gases such as carbon dioxide or nitrogen have a definite depressing or blanketing effect upon gas explosions. In fact, if sufficient carbon dioxide be added to a highly inflammable gas mixture, it may be rendered non-explosive in spite of the presence of adequate oxygen necessary for the combustion.[9]

Dust suspensions follow much the same principles as gas mixtures with the exception that humidity of the air apparently plays a more important part. Dusts which most frequently cause explosions are of organic nature (coal, starch, grain products, sugar, etc.), or finely divided dust of metals (e. g., aluminum) which are easily oxidized.

Explosions of combustible gas or dust mixtures may be exceedingly violent but are always of the "low explosive" type. The damage is of the "push" type rather than the pulverizing, shattering type, although the damage may be very extensive. (See Fig. 7.)

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[8] Values taken chiefly from U. S. Bureau of Mines Bulletin No. 279—"Limits of Inflammability of Gases and Vapors," by H. F. Coward and G. W. Jones (1931).

* Depending upon nature of container, method of ignition and purity of acetylene.

[9] "Inflammability of Mixed Gases," by G. W. Jones (1929); U. S. Bureau of Mines Technical Paper No. 450.

Investigation of Explosions

As has been previously outlined, the examination of the scene of an explosion will often enable one to draw quite reliable conclusions as to the *nature* of the explosive causing the damage, *i. e.*, whether the material was of the *high* or *low* explosive type. Interrogation of witnesses as to the nature of the sound of the explosion, the amount and color[10] of smoke and the violence of concussion as evidenced by ringing of the ears may be of value in corroborating the results of visual examination. The occurrence of a fire in adjacent combustible material will also assist in determining whether a high or low explosive was involved. Needless to say, a thorough inquiry should be made into the possible storage or use of explosive or rapidly combustible materials in the locality of the explosion, and also the possible natural or accidental means of igniting such explosives.

As to which particular member of either class of explosives was involved, the question frequently cannot be answered with certainty. Some explosives are exceedingly difficult to detonate and particles of unexploded material such as damp dynamite or inadequately detonated TNT may be found at the scene. This is rather rare. Some experienced blasters claim that they can recognize different explosives by the odor of their combustion products. The accuracy of such observations is problematical, particularly where the legal tests of certainty are applied.

In addition to a determination of the nature of the explosive from the type of damage produced ("push" type of damage in *low* explosives and localized violent shattering damage with *high* explosives) the debris should be very carefully searched for physical evidence which may give clues as to the type of container or the exploding mechanism. These may consist of exploded pieces of pipe, a can or other container, wrappings of cloth, electrician's tape, rope, wire, fragments of burned fuse, fragments of blasting caps,[11] etc. The waxed paper wrappings of dynamite sticks burn completely when the explosive is detonated unless the dynamite is too damp to explode properly or is ineffectively detonated.

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[10] The color of the smoke produced often depends upon the proportion of oxygen available for the explosion or combustion, rather than upon the particular material which explodes.

[11] The fragments of an exploded blasting cap are exceedingly small and are rarely found. Because of their extreme velocity, even such minute particles may cause fatal wounds. See Wood, R. W., "Optical and Physical Effects of High Explosives." Proc. Roy. Soc. London *157:* 249-261 (1936).

Particularly important are any parts of clockwork mechanisms, wire, unusual bits of metal or foreign material which may have formed a part of the igniting mechanism. While the examination of these is not a matter of chemical analysis, evidence obtained from them may be of great value in demonstrating the origin of the bomb or infernal machine, and in implicating the makers. In an investigation of the dynamiting of the powerhouse of a coal mine in Illinois, portions of wire attached to the alarm clock igniting mechanism were shown to have the same microscopic drawing-die markings as similar wire found in the radio repair shop of one of the suspects. Also a strip of adhesive tape used in the construction of the bomb, when compared with that remaining on a roll in the "first aid" cabinet of the repair shop, proved that the tape from the bomb had been torn from that particular roll. These circumstances were very important in securing a conviction of the guilty persons.[12]

The Examination of Suspected Bombs

In many instances bombs or suspected bombs are discovered before they have exploded. Just what procedure is to be adopted in such an instance? The natural impulse is to get away from the vicinity as quickly as possible and this unquestionably is the safest. But the investigator or police officer, and especially those unsung heroes of the bomb squad of our metropolitan police departments, find it part of their duty to cope with the situation quickly and intelligently, placing their own safety second to that of other persons who might be seriously injured by an explosion. The literature contains few suggestions as to the best procedure to adopt and many of the reports[13] are written in a popular style and are very vague as to technique.

There is no general routine which may be followed for safely investigating all suspected bombs. Techniques which are safe for handling one type may be exceedingly hazardous for another. The popular idea that water inactivates explosives and that soaking a bomb in water renders it harmless is not always valid. Certain explosives such as cast TNT, or blasting gelatin are not affected by water. Furthermore, with a bomb containing metallic potassium,

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[12] This case was investigated and the examinations described above were made by members of the staff of the Scientific Crime Detection Laboratory of Northwestern University School of Law. See appellate court decision in *People* v. *McDonald, et al.,* 365 Ill. 233, 6 N. E. (2d) 182 (1937). This investigation will be reported in greater detail in a subsequent issue of this *Journal.*

[13] See bibliography appended to final section of this article.

metallic sodium, or calcium phosphide, water may be just the wrong inactivating agent to apply. In general, kerosene or light lubricating oil is a better quenching agent than water. Soaking in oil or water will have no effect upon a bomb contained in a water-tight case. A further objection to the use of liquids for inactivating bombs is that the liquid contamination renders subsequent chemical analysis difficult or impossible. At least it is impossible for the chemist to state positively that the contents of the bomb constituted a high explosive, when, as a matter of fact, they were actually non-explosive when he received them. The condition of the explosive *prior* to the application of liquid then becomes a matter of speculation which gives rise to those "reasonable doubts" which are so fatal to the successful prosecution of a criminal case.

If a police officer finds a bomb with a sputtering fuse, the amount of unburned fuse may often be ascertained at a glance. The officer must use his own judgment as to whether it is advisable to take the heroic measure of pulling the fuse out of the bomb, or the more cautious measure of retiring to a safe distance and warning others to keep away until after the explosion has taken place. Safety fuse burns at a rate of 30 to 40 seconds per linear foot and one may guess at the length of time remaining before the explosion from the amount of unburned fuse. Some types of safety fuse are very deceptive and one cannot tell from the outside appearance just how far the burning has progressed. In any event, pulling a burning fuse from a bomb is a reckless procedure and errors in judgment are accompanied by disastrous effects. After warning persons away from the suspected bomb, and if the explosion does not take place within a reasonable time, the officers of the bomb squad should be notified. These officers should also be called to take charge of any packages or articles not possessed of a sputtering fuse but suspected of being bombs. Citizens and police officers should be emphatically warned against touching, moving or opening suspected bombs.

About five years ago a postal inspector in one of our Eastern cities noticed that several packages, all identical in size, shape, and weight were being sent by parcel post to prominent persons of foreign ancestry. They were all addressed in the same handwriting. These facts did not arouse curiosity; the peculiar circumstance which caused suspicion was that the declared contents of the packages was different in each instance. In accordance with his duty, the postal inspector opened one of the packages. A terrific explosion resulted which killed the inspector and wrecked the room of the post office. An expert from one of the explosives companies located on the eastern seaboard was summoned to investigate the remaining packages. He, too, was too daring or hasty in making his examination and met the same fate as the postal inspector.[14] While most unexploded bombs are not so dangerous as this, it is extremely hazardous for unskilled persons to attempt to open them or even handle them. Even experienced investigators can easily do the wrong thing; and usually a person only makes one such mistake.

When officers of the bomb squad are called to take charge of a package suspected of being a bomb, there is a regular series of procedures which may be followed to combine maximum safety with most effective investigation. These are listed in the order in which they should be applied:

(1) Inspect the package, using gloved hands (so as not to add your own fingerprints to any which might have been left on the package). During this inspection the package should be handled gently and as little as possible. It should not be turned on its side or upside down. Some bombs are constructed with igniting mechanisms, which set off the explosive as soon as certain liquids are spilled. Others may be fitted with mercury contact switches which function when the position of the package is radically altered. In any event, materially changing the position of the package is fraught with danger. While maintaining the package in its original position, the investigator should listen carefully for the ticking of a clockwork mechanism. This can best be done by a rubber tipped stethoscope, although one can put his ear against the package and listen. Naturally, all packages which emit a ticking sound are not infernal machines and one frequently is chagrined to find upon subsequent investigation that the ticking suitcase merely contains an inoffensive alarm clock. However, it is suicidal to take chances with ticking packages.

(2) Whether or not the package emits a ticking sound, it should be carried by the bomb squad officers to a bomb-proof for "aging." Precautions against obliterating fingerprints, adding other fingerprints or turning the package upside down or on its side should be taken as outlined in the preceding section. The route to the bomb-proof should be the shortest one which avoids crowded sections of the city. Needless to say, during transportation the

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[14] See reference No. 6 of bibliography.

suspected bomb should be carried with the minimum of shock or jarring.

The bomb-proof should be an enclosure about 10 feet square constructed of steel-reinforced concrete with walls 2 feet thick and about 9 feet high, covered by a light roof composed of a wooden framework and tar roofing paper. In the event of an explosion, the force would be directed upward, wrecking the light roof and doing comparatively little damage to the walls. A 1½ inch diameter steel rod should pass through the center of opposite walls about 3 feet from the ground with a sturdy wood board table top 2 feet square bolted to it. To one end of the bar passing through the wall of the bomb-proof a large crank should be attached. By this crank, the board (to which the suspected bomb is strapped) may be turned upside down. The crank should be fitted with a fastening so that it may be bolted tightly in position when the table is horizontal. Access may be had to the bomb-proof by means of a stairway on the outside and a removable ladder on the inside, which is reached by a trapdoor in the roof. The interior of the bomb-proof should be illuminated by electric light.

(3) The suspected bomb should be carried upright into the bomb-proof, set on the table top, and then strapped carefully but firmly to the table top in an upright position. After exit is made from the bomb-proof and the trapdoor in the roof closed, the suspected bomb should be permitted to "age" for at least 48 hours. During that interval any clockwork mechanism will have had an opportunity to function and set off the bomb. At the end of this period the crank at the end of the steel rod outside the bomb-proof should then be turned over so that the table top inside is turned upside down. If no explosion results the bomb may be further examined.

(4) The bomb should be photographed in its various aspects, taking particular care to record any writing or hand printing. A ruler or scale placed alongside the package while taking the photograph will give a permanent index of size relationships. The handwriting or printing may be of value to the document examiner later in tracing the origin of the package.[15]

(5) The outside of the bomb should be dusted for fingerprints and the wrappings later retained for treatment with iodine vapors, osmic acid fumes, or a silver nitrate solution for the restoration of latent fingerprints.

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[15] See evidence in Magnuson case, 2 Amer. Jour. Pol. Sci. 121 (1931).

(6) The package should then be examined by X-rays, using a fluoroscope. Unless the container is of metal (other than aluminum) it will be possible to locate any objects in the package which are opaque to X-rays, especially such significant materials as clockwork or tripper mechanisms, batteries, wire, switches, and most important of all, blasting caps.

(7) The opening of the suspected package is somewhat hazardcus, even with all the foregoing information. If the container is of metal, X-rays are of no value in locating possible trigger mechanisms or switches. The wrong way to get at the contents of the package (unless the X-ray has demonstrated the *absence* of electrical contact devices or trigger mechanisms) is to open it in the intended way. If the container is of sheet metal with soldered joints, these can be opened by setting the container in a tray of metallic mercury. Mercury will form an amalgam by contact with the solder and the joints may be opened without resorting to violent force or to the dangerous heat of a soldering iron. If the container is of the nature of a pipe bomb (see Figure 4), one is required to corrode away the pipe joint with *dilute* acids. Ordinarily with a pipe bomb filled with gunpowder, it would be safe to apply a pipe wrench to the cap of the bomb and unscrew it. But there is always a possibility that the pipe bomb might be filled with some more sensitive explosive such as a chlorate-sugar mixture. Using physical force for the unscrewing of the cap in that instance might set off the chlorate mixture. The slower but safer way is to set the pipe bomb in an upright position in a glass or porcelain dish. Dilute (10%) sulphuric acid is placed in the dish to a height of about one-quarter to one-half inch above the lower cap joint. The acid will slowly corrode away the pipe threads and finally permit the cap to be removed without force. The spent acid usually has to be replaced by fresh 10% acid when the corrosive action slows down. By this process, the explosive in the lower portion of the bomb is moistened with dilute acid, but the dry explosive in the upper part of the bomb may be removed and used for analysis.

Packages which are transparent to X-rays and which are seen to be safe, may be opened without danger. If they are observed to contain a blasting cap, this should be protected against any type of violent force. The minimum of force should be used in opening any container. The contents should be placed in clean, dry- moisture-proof, cork stoppered, wide-mouth bottles and weighed. The blasting cap (if any) and fuse should be kept separate from the remainder of the explosive. These various parts are then photographed and submitted to examination and chemical analysis as outlined later. This analysis is necessary to prove beyond all doubt that the material *is* explosive. If sufficient explosive material is available, a portion should be taken out into the bomb-proof and exploded by the proper mechanism (fuse or blasting cap). If such a sample explodes, that fact is, in itself, excellent proof of the nature of the material in question.

If the package, upon X-ray examination, appears to be an infernal machine, it is important to locate the blasting cap or igniting mechanism and disconnect or remove these before working on other parts of the bomb. If the container is of wood, cardboard, paper, or cloth, it is carefully cut into, avoiding the tripper or switch mechanism and directing the opening toward the blasting cap or igniting mechanism. A sharp penknife or scalpel is satisfactory for making this dissection. Having made the necessary opening, any wires leading to an electric blasting cap are severed. The fact that this has been accomplished is established by a second X-ray fluoroscopic examination. Having disconnected the igniting mechanism, the hole in the package may be enlarged to permit access to batteries which are then isolated by severing the wires leading from them. It is then safe, or at least reasonably safe to proceed to the main body of the explosive. In this way the package may be opened, starting with the inactivation of the most dangerous element and gradually working toward the explosive itself.

One does not need to observe every detail in the above series of observations in every case. A cursory examination of many suspected bombs will show them to be mere packages of merchandise or lost luggage. Nevertheless, whenever there is a doubt in the mind of the investigator, it is safest to take the slower method of getting at the contents of the package.

Types of Explosives Used in Bombs

Of the *low* explosives, gunpowder, either black, smokeless or semi-smokeless is employed. This may be set off by the flame from a percussion cap, from fuse or by a fine fuse wire which is heated by the passage of an electric current. To be effective, the powder must be tightly confined and the container filled so as to leave little air space which might have a cushioning action. Powder bombs of the type shown in Figure 4 are commonly known as "scare bombs."

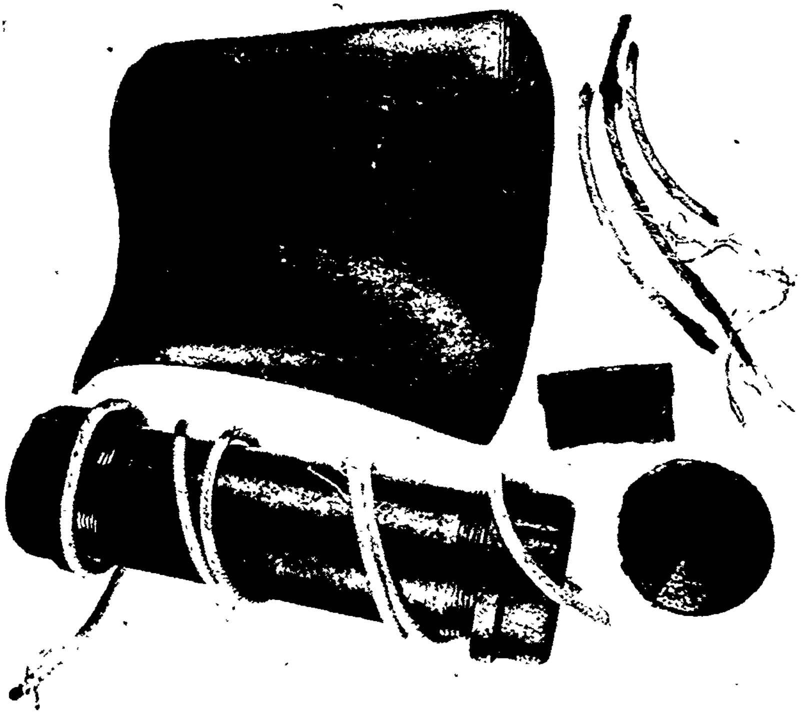

FIGURE 4

A *low* explosive (gunpowder) bomb before and after explosion. Note the "push" effect and the absence of the shattering effect of the gunpowder in splitting the steel pipe along its seam and cracking the iron pipe caps.

They make considerable noise but do comparatively little property damage. Unless one is close at hand and happens to be struck by pieces of the cracked pipe caps, there is little serious hazard to life or limb. Such bombs are used chiefly for purposes of intimidation.

The *high* explosive most frequently used in bombs is nitroglycerine[16] or one of its compounds. Nitroglycerine itself is used by safecrackers in the form of "soup" which is poured into the crack of a safe door and then exploded by a blasting cap placed at the point of entrance. Nitroglycerine is fairly sensitive to shock and it becomes very capricious, particularly when it is slightly acid from improper washing or from slow decomposition. For this reason, it is rarely used in bombs.

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[16] More correctly named *glyceryl trinitrate.*

Dynamite is the common term for explosives which are prepared by causing nitroglycerine (or similar nitric acid esters of polyhydric alcohols such as ethylene glycol dinitrate) to be absorbed in infusorial earth, dried wood pulp, wood flour, or similar porous materials. Since nitroglycerine freezes at winter temperatures to form an unreliable explosive, many dynamites are prepared with nitroglycerine mixed with some freezing-point reducing material. Such dynamites are known as "low freezing" dynamites. There are many other classifications of dynamite also. Dynamites in which nitroglycerine is the sole explosive agent and is absorbed into an inert filler are known as *straight* dynamites. In other dynamites where the explosive effect of the nitroglycerine is augmented by mixtures of ammonium nitrate, sodium nitrate, nitrostarch, etc., these are designated as *extra* dynamites. Thus a 40% extra dynamite might only contain 20% of nitroglycerine, although in explosive power (as measured in a ballistic mortar) it is equivalent to a 40% straight dynamite. Extra dynamites containing considerable ammonium nitrate are often known as *ammonia* dynamites. In order to render dynamites safer and to diminish the leakage or seepage of nitroglycerine, this liquid is sometimes gelatinized by the addition of small amounts of nitro-cotton (cellulose nitrate). These are called *gelatin* dynamites and where the entire explosive consists of this gel, it is known as "blasting gelatine." For use in dusty or gassy coal mines, ordinary dynamites produce a dust or gas explosion hazard because of the long flame which they emit. This may be cut down materially by the addition of dissociating substances such as ammonium chloride, which blanket or smother the flame. Such short flame explosives are known as "permissible explosives."

There is a popular notion that high explosives exert their principal force in a downward direction. This is not true. They exert their force equally in all directions. A stick of blasting gelatine detonated on the upper surface of a rock slab will crack the slab, but the same effect would be obtained by exploding the blasting gelatine on the lower surface. Nitroglycerine explosives are all set off, not by a flame (which usually only causes active burning) but a violent shock such as the explosion of a blasting cap. For this purpose Number 6, or preferably Number 8 blasting caps are used. Dynamites are not particularly sensitive to ordinary shocks such as dropping a stick on the floor. Explosions from rough handling are extremely rare except where violent force has been applied.

Nitro-explosives such as trinitrotoluene (TNT) or picric acid are of little importance except in military use. They are insensitive to shock and require a violent explosion to detonate them. In their cast form they are not particularly inflammable. They are too expensive for commercial use and are therefore not readily available.

Mixtures of potassium chlorate[17] with easily oxidizable substances produce highly explosive compounds. The oxidizable substance may be starch, sugar, sulphur, antimony sulphide, nitrobenzol or any readily oxidized material. Chlorate explosives may be set off by flame as well as by blasting cap. They are so sensitive that their use is extremely dangerous and one can never be certain that they will will not explode prematurely. The grinding of potassium chlorate with *any* oxidizable substance is suicidal. Because of its capriciousness, chlorate explosives are rarely used in the manufacture of bombs.

One occasionally finds combustible substances such as thermite[18] in bombs, but these are chiefly of an incendiary nature rather than explosive and will not be discussed here.

Bomb Ignition Mechanisms

While the method of igniting or "setting off" a bomb is limited only by the mechanical ingenuity of its maker, the great majority of ignition mechanisms may be grouped into two general classifications: (1) those dependent upon *physical manipulation* for their actuation, and (2) those arranged to explode at a pre-determined *time.*

Physical Manipulation:

The simplest and perhaps the oldest of the igniting mechanisms dependent upon physical manipulation are those which are set off by *concussion* or violent contact. The bomb may be so arranged that steel balls, stones, glass fragments or other hard material is mixed with shock-sensitive explosives such as mercury fulminate or chlorate mixtures with a result that any violent shock or concussion will grind the explosive between the surfaces of the hard

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[17] Or chlorate of potash: A powerful oxidizing agent rich in available oxygen.

[18] A mixture of powdered metallic aluminum with powdered iron oxide. It burns with the production of heat sufficiently intense to melt its way through iron or other less resistant materials.

material causing an explosion. A variation of this principle involves the breaking of a thin glass tube of strong sulphuric acid by means of the concussion, which acid then explodes a chlorate-containing explosive mixture. These mechanisms are rarely used, largely because they necessarily involve the use of shock-sensitive explosives which are extremely treacherous and dangerous, both to the maker and the thrower of the bomb. Apparently the criminal element prefer not to take such long chances with their own safety.

Another simple manipulative type of ignition is activated by a person tripping over a cord or wire which in turn either trips a hammer mechanism to set off a percussion cap or closes an electrical circuit which operates an electric blasting cap or an electric fuse wire to ignite the bomb. These, again, are easily detected by a suspicious victim and, because of their complexity, are quite uncertain in their operation. They require careful manipulation in their arrangement and cannot be set quickly. For these reasons such mechanisms are rarely used.

It is quite simple to prepare a bomb container which will explode if it is turned on its side or upside down. Crude (and very uncertain) mechanisms involve the release of a trigger-hammer igniting apparatus or the crushing of a thin glass tube of strong sulphuric acid imbedded in a chlorate explosive mixture. To prepare such mechanisms with even a modicum of safety requires unusual mechanical and manipulative skill. A much neater and safer arrangement may be prepared by using a mercury contact switch. This is so arranged with flashlight batteries and an electric blasting cap that so long as the bomb is kept upright, the electrical circuit is open. Turning the package on its side, end, or upside down will cause the mercury to close the circuit, thus igniting the electric blasting cap and setting off the explosive surrounding it.

Other devices are arranged so that the opening of the package (particularly with a hinged cover) will close an electric circuit and set off an electric blasting cap imbedded in the explosive (Fig. 5).[19] Or the opening of the package may set off a trigger-hammer

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[19] One difficulty in preparing bombs with metallic spring contacts which rub each other and complete an electrical circuit during the *opening* of the lid, is that such springs also complete the circuit during the process of *closing* the lid. Unless precautions are taken, this would cause the bomb to explode during its preparation. In the bomb shown in Fig. 6, this was prevented by inserting a knife switch into the circuit. This switch, which was operated by a string passed through a small hole in the bomb-container. was kept *open* while the maker closed the lid. After the lid was closed and the spring contacts were

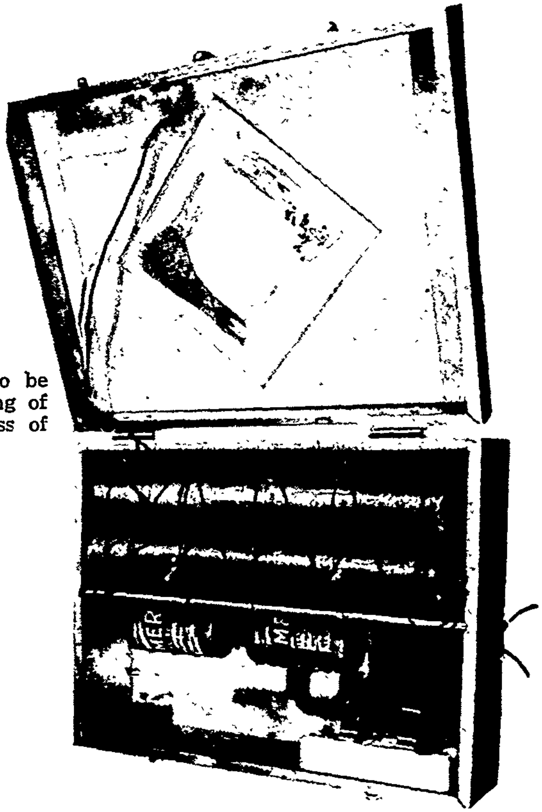

FIGURE 5
Dynamite bomb. Intended to be set off electrically by touching of spring contacts in the process of opening the cover.

mechanism (often made from a mouse trap) which in turn explodes a percussion cap and ignites the explosive. Another variation of this principle is in attaching electric blasting caps to electrical circuits such as those of automobile starters, electric lights, push buttons, etc. The explosive is set off when a person steps on the automobile starter switch, turns on a light or rings a door bell. It is even possible to arrange such electrical circuits so that intense light (daylight or strong artificial light) will activate a photo-electric cell (a so-called "electric eye"), close a circuit and explode an electric blasting cap.

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no longer touching each other, the string was pulled and the switch closed. The string was cut off flush with the outside surface of the box. Thereafter, the opening of the lid would cause the spring contacts to close the circuit, thus exploding the electric blasting cap and the four sticks of dynamite.

Timing Mechanisms:

To cause a bomb to explode at a pre-determined time, one may resort to a variety of methods. The most common type involves the use of a fuse which burns at a fairly constant rate. Knowing the

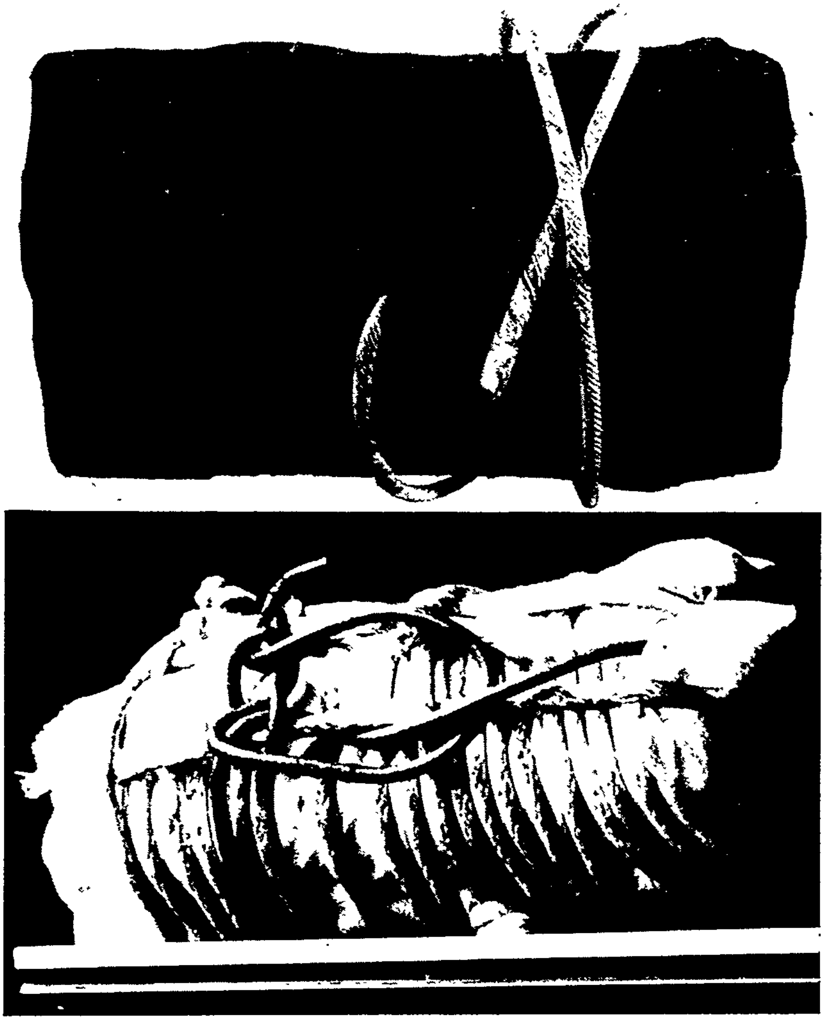

FIGURE 6
Dynamite bombs ignited by safety fuse. These so-called "pineapples" consist of one or more sticks of dynamite, a blasting cap crimped to the end of the safety fuse and imbedded in one of the sticks of dynamite; and the whole held together by rope, electrician's tape, wire, etc.

rate of burning of such fuse, the length of time elapsing between the lighting of the end of the fuse and the explosion of the bomb can be fairly accurately determined by the length of fuse employed. With high explosives, the fuse is crimped into a blasting cap, which, in turn, is imbedded in the explosive (Fig. 6).

The most precise timing devices employ clockwork mechanisms. These are usually prepared from alarm clocks which are so arranged that when the alarm goes off, the turning of the alarm winding key will either close an electric circuit (Figs. 7 and 8) or activate a trigger-hammer mechanism. These can be employed respectively to set off electric blasting caps or explode percussion caps. The accuracy of the exploding time is governed only by the reliability of the clockwork, but the bomb ordinarily must be set less than twelve hours[20] before the intended explosion.

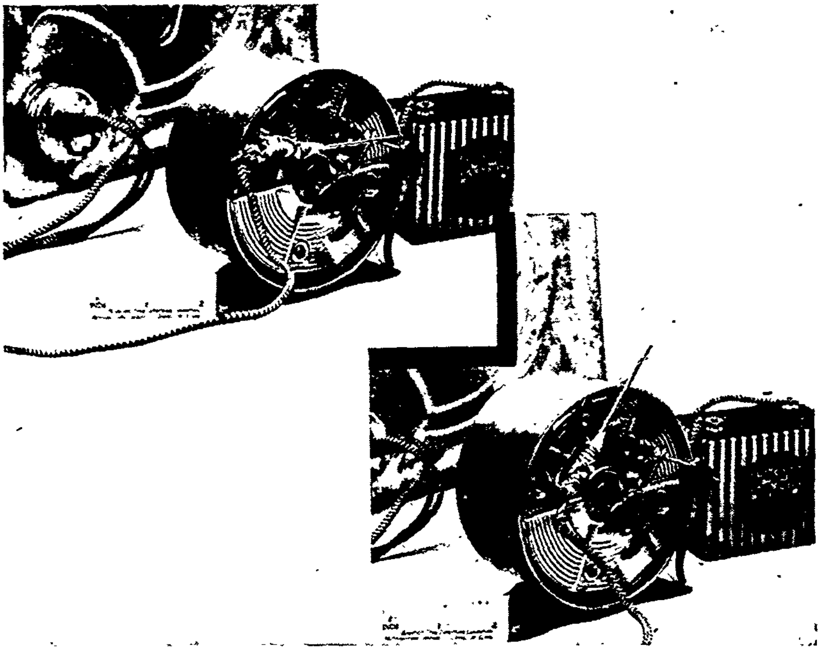

FIGURE 7

Alarm clock electrical ignition mechanism showing "open" and "closed" circuit position.

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[20] Twenty-four hours for an alarm clock which rings only once in twenty-four hours.

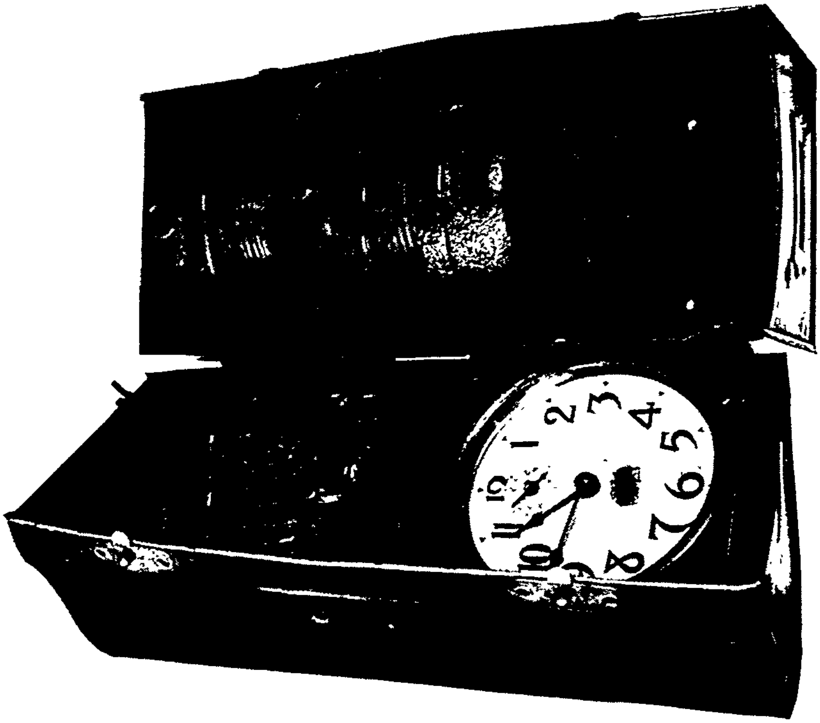

FIGURE 8
Alarm clock time bomb constructed from metal lunch box.

Chemical Timing Mechanisms.[21] These may be employed but they are too unwieldy or uncertain for safe use. In general they depend upon the length of time required for a quantity of sulphuric acid to run through a capillary glass tube or for strong sulphuric acid to corrode its way through a thin cork stopper. In the former procedure, fairly strong sulphuric acid is permitted to flow slowly (drip) through a fine glass capillary tube into a larger glass container. When sufficient acid has flowed through this capillary tube to overflow the large glass container, this overflow, coming into contact with an explosive chlorate mixture, will cause an explosion. The outflow time can be controlled by the diameter of the capillary tube and the viscosity of the sulphuric acid. The outflow time is longer with very small diameter capillary tubes and with high viscosity (high strength) acid. In the other method, a bottle of con-

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[21] See excellent discussion of these in Reference No. 9 of bibliography appended to concluding section of this paper.

centrated sulphuric acid closed with a thin cork stopper is inverted over the chlorate explosive mixture. The length of time required for the acid to destroy the stopper depends upon the thickness of the cork. Neither of these procedures can be regulated precisely as to the time of explosion. Furthermore, there is always the danger of spills or leaks resulting in disastrous premature explosions.

Another method employed more frequently by arsonists involves the use of a candle placed in the center of a bunch of friction matches. The candle is of such length that the exposed wick is above the matches. The matches are placed with their heads upward so that all of the match heads are at the same level. This combination is then placed in a container of kerosene-soaked excelsior or cotton waste which connects to a powder train leading to the explosive. The candle, which must be placed *upright,* burns down to the level of the match heads; these are ignited, and from the resulting flame, the excelsior and powder train are lighted.

It is evident that the above procedures may be varied in many ways, but the principles involved will probably be covered in the foregoing outline. In general, the more complicated the ignition mechanism, the greater the possibility of a premature explosion or a "dud." It is not surprising to find that experienced bombers adhere to the more "fool-proof" procedures of fuse or fuse-blasting cap combinations in preference to the more subtle and intricate clockwork, trigger, or contact mechanisms. Amateurs attempting to prepare intricate infernal machines frequently eliminate themselves in short order.

(*To be concluded in next issue.*)