# Chapter 4 — Method for Experiments on Shell Burst, Preparation and Preliminary Calculations

## 4.1. Experimental Method

Three types of bursting charge were prepared:

a) potassium perchlorate

b) black powder

c) potassium chlorate

The stars were made with potassium perchlorate as the oxidizer.

Sample 5- and 6-inch chrysanthemum shells were prepared with these materials. The shells were reinforced by pasting them with Japanese or Kraft paper. The samples were ranked based on the number of paper layers.

Samples prepared in this way were exploded at a height of 1 m above the ground at night and the movement of the stars was photographed with a still camera (through a revolving shutter driven by a synchronous motor) and also with a 16-mm movie camera.

## 4.2. Aims of the Experiments

(1) To obtain the relationships between the size of the star, density of the star, type of burst charge and the break strength of the shell.

(2) To find the relationships between the velocity of the stars and air resistance, including the effect of the diameter, density, and burning velocity of a star.

## 4.3 Types of Sample Chrysanthemum Shells, their Construction and Preparation

### 4.3.1. Stars

***(1) Types of Stars and their Symbols***

Six types of stars were prepared. They were identified with the following symbols:

| Dia. (mm) | Amber | Blue | Green |
|---|---|---|---|
| 8 | $C_8$ | $B_8$ | $G_8$ |
| 12 | $C_{12}$ | $B_{12}$ | $G_{12}$ |

***(2) Construction of Stars***

Using 3-mm flash stars as the core, compositions SKC, SKB or SKG were pasted in the usual way for round stars. The flash core was used to show clearly the end point of the burning.

### *(3) Compositions of the Stars*

| | |
|---|---|
| SKC$_6$ (Amber Star) | |
| Potassium nitrate | 53.7% |
| Sulfur | 6.5% |
| Pine charcoal | 32.3% |
| Glutinous rice starch | 7.5% |
| SKB (Blue star) | |
| Potassium perchlorate | 64.0% |
| Paris green | 17.0% |
| Pine root pitch | 13.0% |
| Glutinous rice starch | 6.0% |
| SKG (Green star) | |
| Potassium perchlorate | 46.0% |
| Barium nitrate | 32.0% |
| Pine root pitch | 16.0% |
| Glutinous rice starch | 6.0% |
| SBF (Flash) | |
| Barium nitrate | 67.0% |
| Aluminum (fine flake) | 27.0% |
| Glutinous rice starch | 6.0% |
| SBKF (pasted on the flash core to ignite easily) | |
| Barium nitrate | 34.0% |
| Potassium perchlorate | 34.0% |
| Aluminum (fine flake) | 10.0 % |
| Pine root pitch | 8.0% |
| Antimony trisulfide | 9.0% |
| Glutinous rice starch | 5.0% |
| SKC$_8$ (Amber composition called Eight Chrysanthemum) | |
| Potassium nitrate | 48.5% |
| Sulfur | 5.8% |
| Pine charcoal | 38.8% |
| Glutinous rice starch | 6.9% |
| SKC$_5$ (Ignited with Black Powder) | |
| Potassium nitrate | 75.0% |
| Sulfur | 10.0% |
| Hemp charcoal | 15.0% |
| Glutinous rice starch | 1.5% (add.%) |

Eight Chrysanthemum means the ratio of the charcoal to the oxidizer is 8:10 in weight ratio.

### *(4) Diameter of Stars*

Twenty five sample stars were selected from each manufactured batch of stars. The maximum and minimum diameters of each star were measured. In the following tables the maximum and minimum, or minimum and maximum, diameters are recorded for each sample star.

**C$_8$ (Amber star, 8 mm dia.)**

| | mm | mm | | mm | mm |
|---|---|---|---|---|---|
| 1 | 8.38 | 8.52 | 14 | 8.92 | 8.50 |
| 2 | 9.05 | 8.52 | 15 | 8.55 | 8.37 |
| 3 | 8.78 | 8.80 | 16 | 8.76 | 8.76 |
| 4 | 8.51 | 8.69 | 17 | 8.49 | 8.66 |
| 5 | 8.45 | 8.77 | 18 | 8.52 | 8.48 |
| 6 | 8.77 | 8.74 | 19 | 8.40 | 8.35 |
| 7 | 8.60 | 8.75 | 20 | 8.29 | 8.74 |
| 8 | 8.72 | 8.29 | 21 | 8.31 | 8.40 |
| 9 | 8.48 | 8.50 | 22 | 8.49 | 8.40 |
| 10 | 8.25 | 8.47 | 23 | 8.67 | 8.81 |
| 11 | 8.80 | 8.62 | 24 | 8.50 | 8.36 |
| 12 | 8.63 | 8.82 | 25 | 8.71 | 8.59 |
| 13 | 8.88 | 9.35 | Ave. 8.61 mm | | |

The difference between the measured value and the average is denoted by $v$, and the number of the stars is denoted by $n$. The probability deviation $r$ of the diameters of the stars is calculated as follows:

$$r = 0.6745\sqrt{\frac{\sum v^2}{n-1}}$$

$$= 0.6745\sqrt{\frac{0.048134}{50-1}}$$

$$= 0.15 \text{ mm}$$

*Editor's note: There is a 50% probability that an individual result will be in the range given by (average ± probability deviation).*

**$C_{12}$ (Amber Star, 12 mm dia.)**

| | mm | mm | | mm | mm |
|---|---|---|---|---|---|
| 1 | 12.28 | 12.32 | 16 | 12.76 | 12.53 |
| 2 | 12.68 | 12.35 | 17 | 12.11 | 12.00 |
| 3 | 12.69 | 12.29 | 18 | 12.86 | 12.11 |
| 4 | 12.35 | 12.57 | 19 | 11.98 | 11.94 |
| 5 | 12.10 | 12.18 | 20 | 12.33 | 12.12 |
| 6 | 12.18 | 11.83 | 21 | 12.19 | 12.37 |
| 7 | 12.15 | 11.88 | 22 | 12.29 | 12.35 |
| 8 | 12.13 | 12.64 | 23 | 12.28 | 11.82 |
| 9 | 12.35 | 12.50 | 24 | 12.12 | 12.22 |
| 10 | 12.18 | 12.13 | 25 | 11.95 | 11.82 |
| 11 | 12.20 | 12.16 | | | |
| 12 | 12.14 | 11.82 | Ave. = 12.26 mm | | |
| 13 | 12.28 | 12.69 | | | |
| 14 | 12.68 | 12.63 | r = 0.18 mm | | |
| 15 | 12.20 | 12.17 | | | |

**$B_{12}$ (Blue Star, 12 mm dia.)**

| | mm | mm | | mm | mm |
|---|---|---|---|---|---|
| 1 | 12.70 | 12.30 | 16 | 12.30 | 12.48 |
| 2 | 12.39 | 12.38 | 17 | 11.88 | 12.19 |
| 3 | 12.37 | 12.53 | 18 | 12.15 | 12.32 |
| 4 | 11.73 | 11.88 | 19 | 12.25 | 12.44 |
| 5 | 11.67 | 11.70 | 20 | 12.25 | 12.28 |
| 6 | 11.92 | 12.60 | 21 | 11.74 | 11.64 |
| 7 | 12.00 | 12.05 | 22 | 12.69 | 12.62 |
| 8 | 12.16 | 12.23 | 23 | 11.63 | 11.69 |
| 9 | 11.84 | 11.80 | 24 | 12.15 | 12.20 |
| 10 | 11.77 | 11.50 | 25 | 12.41 | 12.27 |
| 11 | 11.61 | 11.82 | | | |
| 12 | 12.16 | 12.15 | Ave. = 12.11 mm | | |
| 13 | 11.88 | 12.73 | | | |
| 14 | 12.65 | 12.34 | r = 0.22 mm | | |
| 15 | 11.64 | 11.87 | | | |

**$B_8$ (Blue Star, 8 mm dia.)**

| | mm | mm | | mm | mm |
|---|---|---|---|---|---|
| 1 | 8.96 | 9.10 | 16 | 8.60 | 8.70 |
| 2 | 8.88 | 8.76 | 17 | 9.07 | 8.96 |
| 3 | 8.87 | 8.76 | 18 | 8.80 | 8.93 |
| 4 | 8.88 | 8.82 | 19 | 8.77 | 8.56 |
| 5 | 9.05 | 9.06 | 20 | 8.84 | 8.83 |
| 6 | 8.45 | 8.57 | 21 | 9.02 | 8.83 |
| 7 | 8.37 | 8.84 | 22 | 8.56 | 8.45 |
| 8 | 8.89 | 8.84 | 23 | 8.95 | 8.75 |
| 9 | 8.34 | 8.45 | 24 | 8.45 | 8.59 |
| 10 | 8.07 | 8.02 | 25 | 8.83 | 8.82 |
| 11 | 8.73 | 8.67 | | | |
| 12 | 9.20 | 9.32 | Ave. = 8.73 mm | | |
| 13 | 8.43 | 8.52 | | | |
| 14 | 8.34 | 8.53 | r = 0.18 mm | | |
| 15 | 8.71 | 8.82 | | | |

**$G_{12}$ (Green Star, 12 mm dia.)**

| | mm | mm | | mm | mm |
|---|---|---|---|---|---|
| 1 | 12.29 | 12.19 | 16 | 12.03 | 12.10 |
| 2 | 12.20 | 12.18 | 17 | 12.19 | 12.39 |
| 3 | 12.29 | 12.33 | 18 | 11.47 | 12.44 |
| 4 | 12.16 | 12.13 | 19 | 12.37 | 12.10 |
| 5 | 12.23 | 12.40 | 20 | 12.38 | 12.10 |
| 6 | 12.05 | 12.17 | 21 | 11.39 | 11.49 |
| 7 | 12.06 | 12.10 | 22 | 12.44 | 12.35 |
| 8 | 11.90 | 12.11 | 23 | 12.30 | 12.07 |
| 9 | 12.44 | 12.17 | 24 | 12.68 | 12.60 |
| 10 | 12.68 | 12.80 | 25 | 12.36 | 12.34 |
| 11 | 12.00 | 12.37 | | | |
| 12 | 12.14 | 12.25 | Ave. = 12.23 mm | | |
| 13 | 12.14 | 12.15 | | | |
| 14 | 12.70 | 12.70 | r = 0.19 mm | | |
| 15 | 12.34 | 12.27 | | | |

**$F_5$ (Flash Star, 5 mm dia.)**

| | mm | mm | | mm | mm |
|---|---|---|---|---|---|
| 1 | 5.0 | 5.0 | 7 | 5.0 | 5.0 |
| 2 | 4.8 | 4.7 | 8 | 4.5 | 4.9 |
| 3 | 4.5 | 4.7 | 9 | 5.0 | 5.0 |
| 4 | 4.7 | 4.7 | 10 | 5.3 | 5.6 |
| 5 | 4.9 | 5.1 | Ave. = 4.92 mm | | |
| 6 | 4.9 | 5.0 | | | |

Note: in this case only ten stars were sampled.

***(5) Mass, Density, Sectional Density, and Bulk Density (Mass of 1 Liter of Stars)***

100 sample stars from a manufactured batch were selected and weighed. The result was divided by 100 to obtain the average mass of one star. The density of the layers was calculated as shown below.

Setting $m_1$ as the mass of a star, $m_2$ as the mass of a flash core, $r_1$ as the radius of a star, and $r_2$ as the radius of a flash core; then $\delta_1$ the density of the colored zone and $\delta_2$ the density of the flash zone were calculated using the following equations:

$$\delta_1 = \frac{m_1 - m_2}{\frac{4}{3}\pi(r_1^3 - r_2^3)}, \ \delta_2 = \frac{m_2}{\frac{4}{3}\pi r_2^3}$$

In the same way, the initial sectional densities (i.e., mass of the star divided by the maximum cross-sectional area) $p_1'$ and $p_2'$ were calculated:

$$p_1' = \frac{m_1}{\pi r_1^2}, \ p_2' = \frac{m_2}{\pi r_2^2}$$

Introducing the data to these equations, we have the results shown in Table 5. The bulk density δ' indicates the total mass of the stars that will fill a 1-liter container.

**Table 5. Average Mass, $m_1$, Density, $\delta_1'$, Sectional Density, $p_1'$, and Bulk Density $\delta_2'$ of the Stars.**

| Param. | Unit | $C_8$ | $B_8$ | $C_{12}$ | $B_{12}$ | $G_{12}$ | Param. | Unit | $F_5$ |
|---|---|---|---|---|---|---|---|---|---|
| $m_1$ | g | 0.47 | 0.55 | 1.30 | 1.47 | 1.56 | $m_2$ | g | 0.11 |
| $\delta_1$ | $g/cm^3$ | 1.34 | 1.59 | 1.48 | 1.62 | 1.64 | $\delta_2$ | $g/cm^3$ | 1.65 |
| $p_1'$ | $g/cm^2$ | 0.80 | 0.93 | 1.11 | 1.27 | 1.34 | $p_2'$ | $g/cm^2$ | 0.58 |
| $\delta_1'$ | kg/l | 0.78 | 0.84 | 0.72 | 0.86 | 0.82 | $\delta_2'$ | kg/l | 1.06 |

***(6) The Burn Time for Stars in the Air when the Stars Are Not Moving***

The stars were placed on the ground and ignited. The burn time was measured with a stopwatch.

**$C_8$**

| | s | | s | | s |
|---|---|---|---|---|---|
| 1 | 2.8 | 11 | 1.6 | 21 | 1.4 |
| 2 | 1.4 | 12 | 1.4 | 22 | 1.8 |
| 3 | 1.8 | 13 | 1.4 | 23 | 1.4 |
| 4 | 1.8 | 14 | 1.2 | 24 | 0.8* |
| 5 | 2.0 | 15 | 0.8* | 25 | 1.0* |
| 6 | 1.8 | 16 | 1.4 | 26 | 1.4 |
| 7 | 1.0* | 17 | 1.6 | 27 | 1.6 |
| 8 | 1.4 | 18 | 2.0 | 28 | 1.8 |
| 9 | 1.8 | 19 | 1.4 | 29 | 1.4 |
| 10 | 1.0 | 20 | 1.8 | 30 | 1.0 |
| Ave. = 1.59 s | | | | | |

Note: The stars marked with * stopped burning before the flash, and they were omitted from the calculation.

$C_{12}$

| | s | | s | | s |
|---|---|---|---|---|---|
| 1 | 2.0 | 11 | 2.2 | 21 | 2.4 |
| 2 | 2.2 | 12 | 2.4 | 22 | 2.6 |
| 3 | 2.4 | 13 | 2.0 | 23 | 2.0 |
| 4 | 1.6* | 14 | 1.4* | 24 | 1.8 |
| 5 | 2.2 | 15 | 2.4 | 25 | 2.2 |
| 6 | 1.4* | 16 | 2.4 | 26 | 2.0 |
| 7 | 1.6* | 17 | 1.2* | 27 | 2.0 |
| 8 | 2.0 | 18 | 1.8 | 28 | 1.6* |
| 9 | 1.6 | 19 | 1.6* | 29 | 2.2 |
| 10 | 2.2 | 20 | 2.4 | 30 | 2.0 |
| Ave. = 2.17 s | | | | | |

Note: The stars marked with * stopped burning before the flash, and they were omitted from the calculation.

$B_8$

| | s | | s | | s |
|---|---|---|---|---|---|
| 1 | 1.2 | 11 | 1.2 | 21 | 1.4 |
| 2 | 1.4 | 12 | 1.2 | 22 | 1.1 |
| 3 | 1.4 | 13 | 1.3 | 23 | 1.2 |
| 4 | 1.2 | 14 | 1.1 | 24 | 1.2 |
| 5 | 1.2 | 15 | 1.2 | 25 | 1.0 |
| 6 | 1.2 | 16 | 1.0 | 26 | 1.0 |
| 7 | 1.0 | 17 | 1.2 | 27 | 1.0 |
| 8 | 1.0 | 18 | 1.2 | 28 | 1.2 |
| 9 | 1.2 | 19 | 1.2 | 29 | 1.2 |
| 10 | 1.6 | 20 | 1.2 | 30 | 1.4 |
| Ave. = 1.20 s | | | | | |

$B_{12}$

| | s | | s | | s |
|---|---|---|---|---|---|
| 1 | 2.0 | 11 | 2.0 | 21 | 2.2 |
| 2 | 2.0 | 12 | 1.8 | 22 | 2.0 |
| 3 | 2.0 | 13 | 1.8 | 23 | 2.0 |
| 4 | 1.8 | 14 | 1.6 | 24 | 2.0 |
| 5 | 2.0 | 15 | 1.8 | 25 | 2.0 |
| 6 | 2.0 | 16 | 1.8 | 26 | 1.8 |
| 7 | 1.8 | 17 | 2.0 | 27 | 2.2 |
| 8 | 2.0 | 18 | 2.2 | 28 | 1.8 |
| 9 | 2.0 | 19 | 2.0 | 29 | 2.0 |
| 10 | 2.0 | 20 | 2.0 | 30 | 2.0 |
| Ave. = 1.95 s | | | | | |

$G_{12}$

| | s | | s | | s |
|---|---|---|---|---|---|
| 1 | 3.2 | 11 | 3.0 | 21 | 3.2 |
| 2 | 2.8 | 12 | 3.0 | 22 | 3.0 |
| 3 | 2.6 | 13 | 3.2 | 23 | 3.0 |
| 4 | 2.8 | 14 | 3.2 | 24 | 3.2 |
| 5 | 3.0 | 15 | 3.0 | 25 | 2.8 |
| 6 | 2.8 | 16 | 2.8 | 26 | 2.8 |
| 7 | 2.6 | 17 | 2.8 | 27 | 3.0 |
| 8 | 3.0 | 18 | 3.2 | 28 | 3.0 |
| 9 | 3.0 | 19 | 3.0 | 29 | 3.2 |
| 10 | 3.0 | 20 | 3.0 | 30 | 3.0 |
| Ave. = 2.97 s | | | | | |

$F_5$

| | s | | s |
|---|---|---|---|
| 1 | 0.6 | 6 | 0.4 |
| 2 | 1.0 | 7 | 0.6 |
| 3 | 0.4 | 8 | 1.0 |
| 4 | 0.2 | 9 | 0.6 |
| 5 | 0.4 | 10 | 0.8 |
| Ave. = 0.60 s | | | |

### 4.3.2. Burst Charge

*(1) Types and Symbols*

Three types were prepared, identified with the following symbols:

| Symbol | Component | Mixing Ratio (%) |
|---|---|---|
| **H** | Potassium chlorate | 75.0 |
| | Hemp charcoal | 25.0 |
| | Glutinous rice starch | 2.0 (Add'l.) |
| **P** | Potassium perchlorate | 70.0 |
| | Hemp charcoal | 18.0 |
| | Sulfur | 12.0 |
| | Glutinous rice starch | 2.0 (Add'l.) |
| **S** | Potassium nitrate | 75.0 |
| | Hemp charcoal | 15.0 |
| | Sulfur | 10.0 |
| | Glutinous rice starch | 2.0 (Add'l.) |

*(2) Construction of the Burst Charge*

The **H** and **P** burst charges were made as follows: The component materials were mixed by sieving, some water was added, and the resulting mixture was kneaded. The burst charge was then coated on cottonseeds and dried in the sun. The **S** burst charge was made as follows: The mixture was placed in a ball mill containing wooden balls and milled for 18 hours. Then the mixture was coated on cottonseeds and dried in the sun. The construction data are as follows.

| | H | P | S |
|---|---|---|---|
| Weight of the charge (in kg) per 1 kg cottonseeds | 1.313 | 1.625 | 1.288 |
| Bulk density of the powdered charge | 0.583 | 0.722 | 0.572 |
| Bulk density of the completed charge | 0.556 | 0.556 | 0.528 |

The thickness of the burst charge that was coated on the cottonseeds was measured as follows: twenty completed grains were selected and they were measured to determine the shortest, middle and the longest diameters, $d_1$, $d_2$, $d_3$, of each ellipsoid, then the grains were washed to remove their coatings and the lengths of the cottonseeds, $d_1'$, $d_2'$, $d_3'$, were again measured. The thickness was calculated by the following formulae.

$$t_1 = \frac{d_1 - d_1'}{2}$$

$$t_2 = \frac{d_2 - d_2'}{2}$$

$$t_3 = \frac{d_3 - d_3'}{2}$$

The thickness (in mm) was obtained from $(t_1 + t_2 + t_3)/3$. The results of the measurement are as follows:

**H**

| No. | $d_1$ | $d'_1$ | $t_1$ | $d_2$ | $d'_2$ | $t_2$ | $d_3$ | $d'_3$ | $t_3$ |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 5.22 | 4.66 | 0.28 | 5.65 | 4.64 | 0.51 | 7.65 | 6.68 | 0.49 |
| 2 | 5.65 | 4.34 | 0.66 | 5.84 | 4.65 | 0.60 | 8.18 | 8.85 | 0.67 |
| 3 | 6.04 | 4.60 | 0.72 | 6.66 | 5.16 | 0.75 | 8.43 | 7.61 | 0.41 |
| 4 | 5.73 | 5.00 | 0.37 | 6.31 | 5.66 | 0.33 | 9.13 | 8.09 | 0.52 |
| 5 | 7.08 | 4.68 | 1.20 | 6.72 | 5.19 | 0.77 | 9.25 | 7.51 | 0.87 |
| 6 | 5.63 | 4.41 | 0.61 | 6.00 | 5.28 | 0.36 | 8.18 | 7.18 | 0.50 |
| 7 | 5.18 | 4.65 | 0.27 | 5.73 | 5.14 | 0.30 | 8.17 | 7.57 | 0.30 |
| 8 | 5.70 | 4.30 | 0.70 | 6.67 | 5.66 | 0.51 | 9.15 | 7.35 | 0.90 |
| 9 | 5.31 | 4.57 | 0.37 | 6.14 | 5.38 | 0.38 | 8.67 | 7.38 | 0.65 |
| 10 | 5.00 | 4.57 | 0.22 | 5.36 | 5.00 | 0.18 | 8.15 | 7.38 | 0.39 |
| 11 | 5.29 | 4.30 | 0.50 | 6.80 | 5.28 | 0.76 | 10.18 | 7.65 | 1.27 |
| 12 | 4.75 | 4.48 | 0.14 | 5.81 | 5.59 | 0.11 | 7.13 | 6.85 | 0.14 |
| 13 | 5.51 | 4.30 | 0.61 | 6.65 | 4.95 | 0.85 | 8.63 | 7.11 | 0.76 |
| 14 | 5.40 | 4.76 | 0.32 | 5.98 | 5.06 | 0.36 | 8.68 | 7.38 | 0.65 |
| 15 | 5.15 | 4.76 | 0.20 | 5.68 | 4.78 | 0.45 | 8.57 | 7.67 | 0.45 |
| 16 | 4.59 | 3.26 | 0.67 | 5.28 | 4.46 | 0.41 | 6.65 | 6.38 | 0.14 |
| 17 | 4.57 | 5.00 | 0.25 | 5.70 | 5.17 | 0.27 | 8.68 | 7.70 | 0.49 |
| 18 | 4.94 | 4.25 | 0.35 | 6.62 | 5.14 | 0.74 | 9.70 | 7.67 | 1.02 |
| 19 | 5.15 | 4.81 | 0.17 | 5.42 | 4.95 | 0.24 | 8.05 | 6.50 | 0.78 |
| 20 | 4.50 | 3.86 | 0.32 | 5.25 | 4.95 | 0.15 | 8.12 | 8.03 | 0.05 |
| Ave. | | | 0.45 | | | 0.45 | | | 0.57 |
| | 0.49 mm | | | | | | | | |

**P**

| No. | $d_1$ | $d'_1$ | $t_1$ | $d_2$ | $d'_2$ | $t_2$ | $d_3$ | $d'_3$ | $t_3$ |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 5.69 | 4.79 | 0.45 | 6.62 | 5.13 | 0.75 | 9.55 | 7.60 | 0.98 |
| 2 | 5.19 | 4.75 | 0.22 | 5.52 | 4.72 | 0.40 | 8.57 | 7.60 | 0.49 |
| 3 | 5.11 | 5.00 | 0.06 | 7.87 | 5.11 | 1.38 | 8.67 | 7.15 | 0.76 |
| 4 | 5.33 | 4.65 | 0.34 | 6.03 | 4.91 | 0.56 | 8.25 | 7.17 | 0.54 |
| 5 | 5.43 | 4.51 | 0.46 | 6.11 | 5.93 | 0.09 | 8.32 | 7.06 | 0.63 |
| 6 | 5.80 | 4.55 | 0.63 | 5.09 | 4.69 | 0.20 | 7.75 | 6.65 | 0.55 |
| 7 | 5.32 | 4.09 | 0.62 | 6.66 | 4.96 | 0.85 | 8.25 | 7.09 | 0.58 |
| 8 | 5.31 | 4.61 | 0.35 | 5.85 | 4.93 | 0.46 | 8.35 | 7.77 | 0.29 |
| 9 | 5.56 | 4.71 | 0.43 | 5.59 | 5.04 | 0.28 | 8.20 | 7.24 | 0.48 |
| 10 | 5.68 | 5.00 | 0.34 | 5.75 | 5.06 | 0.35 | 9.38 | 7.79 | 0.80 |
| 11 | 5.40 | 4.69 | 0.36 | 5.90 | 5.36 | 0.27 | 8.20 | 7.75 | 0.23 |
| 12 | 4.80 | 4.12 | 0.34 | 5.65 | 4.77 | 0.44 | 8.28 | 7.55 | 0.37 |
| 13 | 5.32 | 4.37 | 0.48 | 5.97 | 5.23 | 0.37 | 10.41 | 7.55 | 1.43 |
| 14 | 5.88 | 4.95 | 0.47 | 6.43 | 5.47 | 0.48 | 8.50 | 7.12 | 0.69 |
| 15 | 4.79 | 4.15 | 0.32 | 5.48 | 5.11 | 0.19 | 8.30 | 6.77 | 0.77 |
| 16 | 5.05 | 4.38 | 0.34 | 5.62 | 4.85 | 0.39 | 9.31 | 7.33 | 0.99 |
| 17 | 5.33 | 4.61 | 0.36 | 5.56 | 5.25 | 0.16 | 8.17 | 7.10 | 0.54 |
| 18 | 4.84 | 4.17 | 0.34 | 4.91 | 4.48 | 0.27 | 8.12 | 6.75 | 0.67 |
| 19 | 5.13 | 4.24 | 0.45 | 5.22 | 5.20 | 0.01 | 7.63 | 6.52 | 0.41 |
| 20 | 4.90 | 3.82 | 0.54 | 5.35 | 4.48 | 0.44 | 7.68 | 6.31 | 0.69 |
| Ave. | | | 0.40 | | | 0.41 | | | 0.65 |
| | 0.49 mm | | | | | | | | |

**S**

| No. | $d_1$ | $d'_1$ | $t_1$ | $d_2$ | $d'_2$ | $t_2$ | $d_3$ | $d'_3$ | $t_3$ |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 5.63 | 4.89 | 0.37 | 5.74 | 4.90 | 0.42 | 8.60 | 6.79 | 0.91 |
| 2 | 6.33 | 4.85 | 0.74 | 6.83 | 5.21 | 0.81 | 9.54 | 7.21 | 1.17 |
| 3 | 5.10 | 4.47 | 0.32 | 5.70 | 5.14 | 0.28 | 8.32 | 6.86 | 0.73 |
| 4 | 5.09 | 4.71 | 0.19 | 5.47 | 5.00 | 0.24 | 8.39 | 7.17 | 0.61 |
| 5 | 4.97 | 4.42 | 0.28 | 6.20 | 5.26 | 0.47 | 8.77 | 7.30 | 0.75 |
| 6 | 4.93 | 4.04 | 0.45 | 5.12 | 4.54 | 0.29 | 8.10 | 6.83 | 0.64 |
| 7 | 5.03 | 4.17 | 0.43 | 5.60 | 4.92 | 0.34 | 8.61 | 6.73 | 0.84 |
| 8 | 5.17 | 4.77 | 0.20 | 5.55 | 4.82 | 0.37 | 8.60 | 7.20 | 0.70 |
| 9 | 5.14 | 4.74 | 0.20 | 5.95 | 5.38 | 0.29 | 8.90 | 7.56 | 0.67 |
| 10 | 4.94 | 4.36 | 0.29 | 6.07 | 5.61 | 0.23 | 8.03 | 7.25 | 0.39 |
| 11 | 5.02 | 4.30 | 0.36 | 5.45 | 5.05 | 0.20 | 9.35 | 6.70 | 1.23 |
| 12 | 4.73 | 4.08 | 0.33 | 5.65 | 5.07 | 0.29 | 8.12 | 6.90 | 0.61 |
| 13 | 5.17 | 4.36 | 0.41 | 6.09 | 5.12 | 0.49 | 8.57 | 7.65 | 0.46 |
| 14 | 5.07 | 4.05 | 0.51 | 5.62 | 5.41 | 0.11 | 8.18 | 7.60 | 0.29 |
| 15 | 5.42 | 4.42 | 0.50 | 6.00 | 5.12 | 0.44 | 7.80 | 7.17 | 0.32 |
| 16 | 4.92 | 4.26 | 0.33 | 5.10 | 4.75 | 0.18 | 8.45 | 7.04 | 0.71 |
| 17 | 5.55 | 4.97 | 0.29 | 5.72 | 4.73 | 0.50 | 9.12 | 7.56 | 0.78 |
| 18 | 4.88 | 4.27 | 0.31 | 5.62 | 5.10 | 0.26 | 8.62 | 6.68 | 0.97 |
| 19 | 4.73 | 4.05 | 0.34 | 5.35 | 4.67 | 0.34 | 8.21 | 7.50 | 0.36 |
| 20 | 4.70 | 4.01 | 0.35 | 5.44 | 4.30 | 0.57 | 8.07 | 6.98 | 0.55 |
| Ave. | | | 0.36 | | | 0.36 | | | 0.68 |
| | 0.47 mm | | | | | | | | |

From the above measurements, we see that although the thicknesses are very irregular, the average values are similar, and the values range from 0.47 to 0.49 mm.

***(3) Sensitiveness Test by Drop Hammer***

The results of drop hammer tests for the burst charges, **H**, **P**, and **S** are shown in Figure 13. For comparison the data from tests of picric acid are also shown. The mass of the hammer was 2 kg and the thickness of the tin-foil cover of the sample was 0.05 mm. From the results we see that the **S** burst charge is the most insensitive and **H** and **P** have almost the same sensitiveness. The problem of fireworks safety is very complicated and these data only serve as an indication of the relative sensitiveness.

***(4) Calculation of Characteristic Values of Burst Charges***

*1. Calorimetric Data of Solids and Gases*

*(a) The Internal Energy of Gases*

The internal energies at various temperatures were calculated by means of statistical mechanics, using the normal vibration numbers from spectral analysis with the standard vibration number at 15 °C [$=E_{15\,°C}$ (T)/J kcal/mol)]. They are shown in Table 6.

However, for KCl the author did not have any reliable thermochemical data, and the calculation was conducted as follows:

**15–790 °C**

$$\begin{aligned}(E) &= 0.126\times(790-15)+5.52\\ &= 15.29\ \text{kcal}\end{aligned}$$

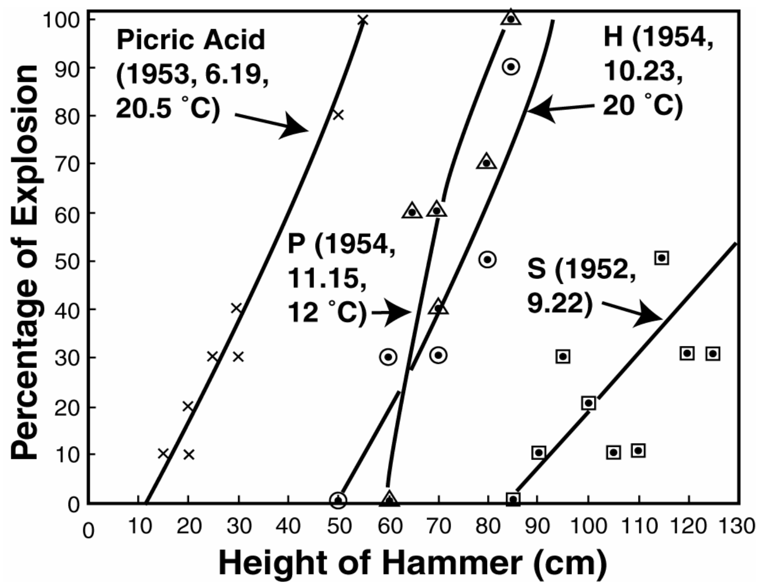



*Figure 13. The results of drop hammer test of burst charges.*

**790–1420 °C**

$$(E)=\left\{\frac{0.0126+0.0060}{2}\right\}\times(1420-790)$$
$$=5.86\text{ kcal}$$

**Greater than 1420 °C**

$$E=\frac{3}{2}R(T-1420-273)\times 2\times\frac{1}{1000}$$
$$=5.958(T-1693)\times 10^{-3}$$
$$=5.96\times 10^{-3}T-10.09\text{ kcal}$$

The sum of the above should be the formula that is applicable for the temperature range up to 1420 °C:

$$E_{KCl}=11.06+5.96\times 10^{-3}\,T$$

*(b) The Internal Energy of Solids*

$\overline{E}$ is the internal energy of 1 gram atom and $C_v$ is the atomic heat, then

$$\overline{E}=9R\Theta\frac{1}{x^4}\int_0^x\frac{x^3dx}{e^x-1}$$

$$C_v=\frac{\partial\overline{E}}{\partial T}=9R\left[4x^{-3}\int_0^x\frac{x^3dx}{e^x-1}-\frac{x}{e^x-1}\right]$$

Here $x=\dfrac{\Theta}{T}$ and $\Theta$ is called the specific temperature.

**Table 6. The Internal Energy of Gases with Temperatures $E_{15\,°C}$ (T)/J kcal/mole .**

| T (K) | $E_{H_2}$ | $E_{N_2}$ | $E_{O_2}$ | $E_{S_2}$ | $E_{CO}$ | $E_{H_2O}$ | $E_{CO_2}$ | $E_{KCl}$ | $E_{SO_3}$ |
|---|---|---|---|---|---|---|---|---|---|
| 1000 | 4.28 | 4.49 | 4.78 | 7.90 | 4.55 | 5.72 | 7.43 | — | 9.30 |
| 1500 | 6.94 | 7.54 | 8.03 | 12.38 | 7.64 | 9.99 | 13.18 | — | 17.20 |
| 2000 | 9.82 | 10.75 | 11.43 | 16.93 | 10.89 | 14.81 | 19.24 | 22.98 | 25.36 |
| 2500 | 12.86 | 14.07 | 14.94 | 21.56 | 14.23 | 19.98 | 25.45 | 25.96 | 33.61 |
| 3000 | 16.01 | 17.43 | 18.54 | 26.26 | 17.61 | 25.37 | 31.73 | 28.94 | 41.96 |
| 3500 | 19.24 | 20.82 | 22.22 | 31.03 | 21.01 | 30.91 | 38.07 | 31.92 | 50.32 |
| 4000 | 22.52 | 24.24 | 25.94 | 35.89 | 24.44 | 36.54 | 44.44 | 34.90 | 58.34 |
| 4500 | 25.85 | 27.66 | 29.71 | 40.82 | 27.87 | 42.24 | 50.81 | 37.88 | 67.08 |

**Table 7. The Values of $C_v$ and $\bar{E}/\Theta$ as a Function of $1/x = T/\Theta$.**

| $\frac{T}{\Theta}$ | $C_v$ | $\frac{\bar{E}}{\Theta}$ | $\frac{T}{\Theta}$ | $C_v$ | $\frac{\bar{E}}{\Theta}$ | $\frac{T}{\Theta}$ | $C_v$ | $\frac{\bar{E}}{\Theta}$ | $\frac{T}{\Theta}$ | $C_v$ | $\frac{\bar{E}}{\Theta}$ | $\frac{T}{\Theta}$ | $C_v$ | $\frac{\bar{E}}{\Theta}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.05 | 0.15 | — | 1.05 | 5.69 | 4.32 | 2.05 | 5.88 | 10.16 | 3.05 | 5.92 | 16.00 | 4.05 | 5.94 | 21.92 |
| 0.10 | 0.45 | 0.05 | 1.10 | 5.71 | 4.60 | 2.10 | 5.88 | 10.47 | 3.10 | 5.92 | 16.30 | 4.10 | 5.94 | 22.22 |
| 0.15 | 1.25 | 0.10 | 1.15 | 5.73 | 4.87 | 2.15 | 5.88 | 10.77 | 3.15 | 5.93 | 16.60 | 4.15 | 5.94 | 22.50 |
| 0.20 | 2.25 | 0.20 | 1.20 | 5.75 | 5.17 | 2.20 | 5.89 | 11.05 | 3.20 | 5.93 | 16.90 | 4.20 | 5.94 | 22.83 |
| 0.25 | 3.00 | 0.35 | 1.25 | 5.77 | 5.45 | 2.25 | 5.89 | 11.35 | 3.25 | 5.93 | 17.20 | 4.25 | 5.94 | 23.14 |
| 0.30 | 3.60 | 0.50 | 1.30 | 5.78 | 5.75 | 2.30 | 5.89 | 11.63 | 3.30 | 5.94 | 17.50 | 4.30 | 5.94 | 23.44 |
| 0.35 | 4.11 | 0.70 | 1.35 | 5.79 | 6.03 | 2.35 | 5.89 | 11.93 | 3.35 | 5.94 | 17.80 | 4.35 | 5.94 | 23.75 |
| 0.40 | 4.46 | 0.70 | 1.40 | 5.80 | 6.34 | 2.40 | 5.89 | 12.21 | 3.40 | 5.94 | 18.10 | 4.40 | 5.94 | 24.05 |
| 0.45 | 4.72 | 1.10 | 1.45 | 5.82 | 6.64 | 2.45 | 5.89 | 12.50 | 3.45 | 5.94 | 18.40 | 4.45 | 5.94 | 24.35 |
| 0.50 | 4.92 | 1.30 | 1.50 | 5.83 | 6.91 | 2.50 | 5.90 | 12.80 | 3.50 | 5.94 | 18.70 | 4.50 | 5.94 | 24.70 |
| 0.55 | 5.10 | 1.60 | 1.55 | 5.84 | 7.21 | 2.55 | 5.90 | 13.10 | 3.55 | 5.94 | 19.00 | 4.55 | 5.94 | 24.97 |
| 0.60 | 5.21 | 1.84 | 1.60 | 5.84 | 7.50 | 2.60 | 5.90 | 13.40 | 3.60 | 5.94 | 19.28 | 4.60 | 5.94 | 25.30 |
| 0.65 | 5.31 | 2.10 | 1.65 | 5.85 | 7.80 | 2.65 | 5.90 | 13.70 | 3.65 | 5.94 | 19.56 | 4.65 | 5.94 | 25.60 |
| 0.70 | 5.40 | 2.40 | 1.70 | 5.85 | 8.07 | 2.70 | 5.90 | 13.97 | 3.70 | 5.94 | 19.86 | 4.70 | 5.94 | 25.27 |
| 0.75 | 5.46 | 2.60 | 1.75 | 5.86 | 8.37 | 2.75 | 5.90 | 14.27 | 3.75 | 5.94 | 20.17 | 4.75 | 5.94 | 26.17 |
| 0.80 | 5.52 | 2.91 | 1.80 | 5.86 | 8.65 | 2.80 | 5.91 | 14.55 | 3.80 | 5.94 | 20.46 | 4.80 | 5.94 | 26.47 |
| 0.85 | 5.56 | 3.20 | 1.85 | 5.87 | 8.95 | 2.85 | 5.91 | 14.85 | 3.85 | 5.94 | 20.75 | 4.85 | 5.94 | 26.75 |
| 0.90 | 5.60 | 3.49 | 1.90 | 5.87 | 9.24 | 2.90 | 5.91 | 15.15 | 3.90 | 5.94 | 21.05 | 4.90 | 5.94 | 27.05 |
| 0.95 | 5.64 | 3.77 | 1.95 | 5.87 | 9.55 | 2.95 | 5.92 | 15.43 | 3.95 | 5.94 | 21.35 | 4.95 | 5.94 | 27.35 |
| 1.00 | 5.66 | 4.25 | 2.00 | 5.88 | 9.83 | 3.00 | 5.92 | 15.71 | 4.00 | 5.94 | 21.63 | 5.00 | 5.94 | 27.65 |

The values calculated from the above formula of $C_v$ and $\bar{E}/\Theta$ as a function of $1/x = T/\Theta$ are shown in Table 7.

In the following paragraphs, brackets [ ] indicate the solid state and parentheses ( ) indicate the liquid state for a substance at normal temperature.

In the calculations, four substances have to be included: carbon [C], potassium sulfate [$K_2SO_4$], potassium oxide [$K_2O$], and potassium sulfide [$K_2S$].

When the atomic heat at high temperature is known, the value at a high temperature is divided by the number of atoms to obtain the value of $C_v$. Then from $C_v$ in Table 7 the value of $T/\Theta$ is obtained. $T$ is known and $\Theta$ is calculated. To obtain the internal energy $E$, the $T/\Theta$ value for each temperatures is calculated for $\Theta$. Then $\bar{E}/\Theta$ is obtained from the column of $T/\Theta$. The internal energy $E$ is obtained by multiplying the value of $\bar{E}/\Theta$ by $\Theta$ and the number of atoms in one molecule. The value of $\Theta$ is shown as follows.[3]

| | [C(graphite)] | [$K_2SO_4$] |
|---|---|---|
| Measured temp. T (K) | 1273 | 280 |
| Molecular specific heat | 4.92 | 31.2 |
| Number of atoms | 1 | 7 |
| Average atomic heat | 4.92 | 4.45 |
| $T/\Theta$ | 0.50 | 0.40 |
| $\Theta$ (K) | 2546 | 720 |

For [$K_2O$] and [$K_2S$] the value of $\Theta$ could not be obtained, so it was roughly calculated using the following formula. Using $C_v$ as $3nR$, we have:

$$E_{[K_2O]} = E_{[K_2S]} = 3nR(T-288)\times\frac{1}{1000}$$
$$= 3\times3\times1.986\times(T-288)\times\frac{1}{1000}$$
$$= -5.15 + 17.87\times10^{-3}T$$

The values calculated in this way are shown in Table 8.

**Table 8. The Internal Energy of Solid Materials $E_{15\,°C}$ (kcal/mole ).**

| T (K) | $E_{[C]}$ | $E_{[K_2SO_4]}$ | $E_{[K_2O]}$ | $E_{[K_2S]}$ |
|---|---|---|---|---|
| 1000 | — | 27.12 | 12.72 | 12.72 |
| 1500 | — | 47.63 | 21.66 | 21.66 |
| 2000 | 2.78 | 68.24 | 30.59 | 30.59 |
| 2500 | 3.88 | 89.31 | 39.53 | 39.53 |
| 3000 | 4.98 | 109.52 | 48.46 | 48.46 |
| 3500 | 6.13 | — | — | — |
| 4000 | 7.26 | — | — | — |

*2. The Characteristic Values of Bursting Charge* (**H**)

*(a) The Composition of 1 kg Mixture Consisting of:*

| Materials | Mixing Ratio (%) | Quantity in 1 kg of Mixture (g) | Chemical Constituents | Composition (%) | Quantity in 1 kg Mixture (g) |
|---|---|---|---|---|---|
| Potassium chlorate | 75 | 735 | $KClO_3$ | 100 | 735 |
| Hemp charcoal | 25 | 245 | C | 82 | 201 |
| | | | $H_2O$ | 10 | 25 |
| | | | Ash | 8 | 19 |
| Glutinous rice starch | 2 | 20 | $C_6H_{10}O_5$ | 87 | 17 |
| | | | $H_2O$ | 13 | 3 |
| | 102 | 1000 | | | 1000 |

*(b) Number of Moles of Components in 1 kg Mixture*

| | | | | |
|---|---|---|---|---|
| $KClO_3$ | = | 735 / 122.58 | = | 6.00 mole |
| C | = | 201 / 12.01 | = | 16.74 mole |
| $H_2O$ | = | 28 / 18.02 | = | 1.55 mole |
| $C_6H_{10}O_5$ | = | 17 / 162.16 | = | 0.10 mole |

*(c) Number of Gram Atoms in 1 kg Mixture*

| | K | Cl | O | C | H |
|---|---|---|---|---|---|
| $KClO_3$ | 6.00 | 6.00 | 18.00 | — | — |
| C | — | — | — | 16.74 | — |
| $H_2O$ | — | — | 1.55 | — | 3.10 |
| $C_6H_{10}O_5$ | — | — | 0.50 | 0.60 | 1.00 |
| | 6.00 | 6.00 | 20.05 | 17.34 | 4.10 |

*(d) Explosive Reaction*

The reaction is assumed to be as follows.

1 kg of mixture = $x\ CO_2 + y\ H_2 + z\ CO + u\ (H_2O) + \alpha\ [KCl] + Q$

Here $Q$ denotes combustion heat (explosion heat). On the other hand, introducing the water gas reaction:

$CO + H_2O$ <—> $CO_2 + H_2$

$$\frac{z\cdot u}{x\cdot y} = K(T)$$

Using the following calculated data by statistical mechanics:[6] where

$$K(T) = \frac{P_{CO}P_{H_2O}}{P_{CO_2}P_{H_2}}$$

See Table 9.

**Table 9. Values of *K*(*T*) for Various Temperatures.**

| T | K(T) | T | K(T) | T | K(T) | T | K(T) |
|---|---|---|---|---|---|---|---|
| 1000 | 0.72 | 2000 | 4.46 | 3000 | 7.09 | 4000 | 8.44 |
| 1100 | 1.04 | 2100 | 4.81 | 3100 | 7.29 | 4100 | 8.55 |
| 1200 | 1.39 | 2200 | 5.12 | 3200 | 7.46 | 4200 | 8.63 |
| 1300 | 1.78 | 2300 | 5.42 | 3300 | 7.59 | 4300 | 8.77 |
| 1400 | 2.16 | 2400 | 5.71 | 3400 | 7.76 | 4400 | 8.84 |
| 1500 | 2.57 | 2500 | 5.97 | 3500 | 7.87 | 4500 | 8.88 |
| 1600 | 2.97 | 2600 | 6.23 | 3600 | 8.01 | 4600 | 8.96 |
| 1700 | 3.36 | 2700 | 6.47 | 3700 | 8.18 | 4700 | 9.03 |
| 1800 | 3.74 | 2800 | 6.70 | 3800 | 8.27 | 4800 | 9.08 |
| 1900 | 4.11 | 2900 | 6.59 | 3900 | 8.36 | 4900 | 9.10 |

*(e ) Calculation of Characteristic Values from the Balance of Materials:*

$$\begin{aligned} \mathrm{C} &= x + z \\ \mathrm{O} &= 2x + z + u \\ \mathrm{H} &= 2y + 2u \\ \mathrm{KCl} &= \alpha \end{aligned}$$

From the heat of explosion $Q$

$$\begin{aligned} Q &= xq_{\mathrm{CO_2}} + zq_{\mathrm{CO}} + uq_{(\mathrm{H_2O})} + \alpha q_{[\mathrm{KCl}]} - q + \Delta q \\ &= xE_{\mathrm{CO_2}} + yE_{\mathrm{H_2}} + zE_{\mathrm{CO}} + uE_{(\mathrm{H_2O})} + \alpha E_{[\mathrm{KCl}]} \end{aligned}$$

Here, $q$ denotes the heat of formation; $\Delta q$, the value of the correction of $q$ from constant pressure to constant volume and equal to 0.57 kcal/mol gas (at the temperature of explosion).

$$\begin{aligned} q_{\mathrm{CO_2}} &= 97.80 \text{ kcal} \\ q_{\mathrm{CO}} &= 29.70 \text{ kcal} \\ q_{(\mathrm{H_2O})} &= 68.31 \text{ kcal} \\ q_{[\mathrm{KCl}]} &= 105.6 \text{ kcal} \\ q_{[\mathrm{KClO_3}]} &= 95.9 \text{ kcal} \end{aligned}$$

$$\begin{aligned} q &= 6.00\ q_{\mathrm{KClO_3}} + 1.55\ q_{(\mathrm{H_2O})} + 0.10\ q_{[\mathrm{C_6H_{10}O_5}]} \\ &= 6.00 \times 95.9 + 1.55 \times 68.31 + 0.10 \times 226.8 \\ &= 704.0 \text{ kcal} \end{aligned}$$

From the above formula we have:

$$\begin{aligned} y &= \mathrm{C} + \frac{1}{2}\mathrm{H} - \mathrm{O} + x' = x - 0.66 \\ z &= \mathrm{C} - x = 17.34 - x \\ u &= \mathrm{O} - \mathrm{C} - x = 2.71 - x \end{aligned}$$

Therefore

$$\begin{aligned} \Delta q &= 0.57 \times (x + y + z + u + \alpha) \\ &= 0.57 \times \left(\mathrm{C} + \frac{1}{2}\mathrm{H} + \alpha\right) = 0.57 \times 25.39 \\ &= 14.47 \end{aligned}$$

$$\begin{aligned} Q_1 &= xq_{\mathrm{CO_2}} + zq_{\mathrm{CO}} + uq_{(\mathrm{H_2O})} + \alpha q_{[\mathrm{KCl}]} - q + \Delta q \\ &= 97.80x + 29.70(17.34 - x) + \\ &\quad 68.31(2.71 - x) + 6.00 \times 105.6 - \\ &\quad 704.0 + 14.47 \\ &= 0.21x + 644.19 \end{aligned}$$

*Approximate Value of Explosion Temperature $T_v$*

When we disregard the mol of $CO_2$ ($x \doteqdot 0$), we have $Q_1 = 644$ kcal.

From the relation of internal energy, disregarding $x$ and $y$, we have:

$$Q_2 = zE_{\mathrm{CO}} + uE_{\mathrm{H_2O}} + \alpha E_{\mathrm{KCl}}$$

Then we have:

$T = 2000$ K $Q_2 = 10.89 \times 17.34 + 2.71 \times (14.81 + 10.54) + 6 \times 22.78 = 395.41$

$T$ = 3000 K  $Q_2$ = 17.61 × 17.34 + 2.71 ×
(25.97 + 10.54) + 6 × 28.94 = 576.32

$T$ = 4000 K  $Q_2$ = 24.44 × 17.34 + 2.71 ×
(36.54 + 10.54) + 6 × 34.90 = 760.78

| T(K) | $x E_{CO_2}$ (T) | $y E_{H_2}$ (T) | $z E_{CO}$ (T) | $u E_{H_2O}$ (T) | $\alpha E_{KCl}$ (T) | $Q_2$ (kcal) |
|---|---|---|---|---|---|---|
| 3000 | 55.84 | 17.61 | 274.36 | 24.10 | 173.64 | 548.55 |
| 3500 | 67.00 | 21.16 | 327.34 | 29.36 | 191.52 | 636.38 |
| 4000 | 78.21 | 24.77 | 380.78 | 34.71 | 209.40 | 727.87 |

( $E_{H_2O}$ was added with the latent heat 10.54 kcal/mol for vaporization.)

When we read the point $Q_1$ = 644 kcal on the $T$ vs $Q$ graph, we have an approximate value:

$T_v$ = 3360 K

*More Accurate Calculation of $T_v$.*

From Table 9 we have an equilibrium constant $K(T)$ = 7.69 for $T_v$ = 3360 K. Therefore:

$$\frac{z \cdot u}{x \cdot y} = \frac{(17.34 - x)(2.71 - x)}{x(x - 0.66)} = 7.69$$

From the formula we have, $x$ = 1.76, therefore:

$$y = x - 0.66 = 1.10 \text{ mol}$$
$$z = 17.34 - x = 15.58 \text{ mol}$$
$$u = 2.71 - x = 0.95 \text{ mol}$$

Therefore:

$$Q_1 = 0.21x + 644.19 = 0.21 \times 1.76 + 644.19$$
$$= 645 \text{ kcal}$$

From Tables 6 and 8 having the values $E$ and calculating $Q_2$, we have:

Reading the value for $T_v$ at $Q_2$ = 645 kcal on the $T$ vs $Q$ graph gives the explosion temperature $T_v$. Thus we have:  $T_v$ = 3550 K

Repeating the calculation in the same way, using this value of $T_v$, the result did not change.

The specific volume is calculated as:

$$V_o = (x + y + z + u + \alpha) \times 22.41$$
$$= (1.76 + 1.10 + 15.58 + 0.95) \times 22.41$$
$$= 569 \text{ l}$$

The force of explosives is therefore

$$f_H = 0.3782 V_o T_v$$
$$= 0.3782 \times 569 \times 3550$$
$$= 0.736 \times 10^6 \text{ dm}$$

*3. The Characteristic Values of Burst Charge* (**P**)

*(a) The Composition*

| Materials | Mixing Ratio (%) | Quantity in 1 kg Mixture (g) | Chemical Constituents | Composition (%) | Quantity in 1 kg Mixture (g) |
|---|---|---|---|---|---|
| Potassium perchlorate | 70 | 686 | $KClO_4$<br>$H_2O$<br>others | 99.3<br>0.2<br>0.5 | 681<br>2<br>3 |
| Hemp charcoal | 18 | 176 | C<br>$H_2O$<br>Ash | 82.0<br>10.0<br>8.0 | 144<br>18<br>14 |
| Sulfur | 12 | 118 | $S_2$ | 100.0 | 118 |
| Glutinous rice starch | 2 | 20 | $C_6H_{10}O_5$<br>$H_2O$ | 87.0<br>13.0 | 17<br>3 |
| | 102 | 1000 | | | 1000 |

*(b) Number of Moles in 1 kg of Mixture*

| | | | | |
|---|---|---|---|---|
| $KClO_4$ | = | 681/138.55 | = | 4.91 |
| C | = | 144/12.01 | = | 11.99 |
| $S_2$ | = | 118/64.12 | = | 1.84 |
| $H_2O$ | = | 23/18.02 | = | 1.27 |
| $C_6H_{10}O_5$ | = | 17/162.14 | = | 0.10 |

*(c) Number of Gram Atoms in 1 kg Mixture*

| | K | Cl | O | C | S | H |
|---|---|---|---|---|---|---|
| $KClO_3$ | 4.91 | 4.91 | 19.64 | — | — | — |
| C | — | — | — | 11.99 | — | — |
| $S_2$ | — | — | — | — | 3.68 | — |
| $H_2O$ | — | — | 1.27 | — | — | 2.54 |
| $C_6H_{10}O_5$ | — | — | 0.50 | 0.60 | — | 1.00 |
| | 4.91 | 4.91 | 21.41 | 12.59 | 3.68 | 3.54 |

*(d) Explosive Reaction*

The reaction of the explosion would proceed according to the following process:

**Reaction (1)**

$$\underset{1.84}{KClO_4} + \underset{1.84}{S_2} = \underset{1.84}{KCl} + \underset{3.68}{2\,SO_2}$$

The remaining $KClO_4$ is

$$4.91 - 1.84 = 3.07 \text{ mole}$$

**Reaction (2)**

$$\underset{3.07}{KClO_4} + \underset{6.14}{2\,C} = \underset{3.07}{KCl} + \underset{6.14}{2\,CO_2}$$

The remaining C is

$$12.59 - 6.14 = 6.45 \text{ mole}$$

**Reaction (3)**

Reduction of $SO_2$

$$\underset{3.23}{SO_2} + \underset{6.45}{2\,C} = \underset{6.45}{2\,CO} + \underset{1.62}{\tfrac{1}{2}\,S_2}$$

The remaining $SO_2$ is

$$3.68 - 3.23 = 0.45 \text{ mole}$$

**Reaction (4)**

$$\underset{0.45}{CO_2} + \underset{0.45}{SO_2} = \underset{0.45}{CO} + \underset{0.45}{SO_3}$$

The remaining $CO_2$ is

$$6.14 - 0.45 = 5.69 \text{ mole}$$

From the above calculations, the substances produced should be 0.45 mole $SO_3$, 1.62 mole $S_2$, and 4.91 mole (1.84 + 3.07) KCl and $CO_2$, CO. The latter would be in equilibrium with $H_2O$ and $H_2$, in the gas reaction. Therefore, the reaction equation should be given as

$$1 \text{ kg mixture} = x\,CO_2 + y\,H_2 + z\,CO + u\,(H_2O) + 0.45\,SO_3 + 1.62\,(S_2) + 4.91\,(KCl) + Q \text{ (reaction heat).}$$

From the number of atoms

$$C = x + z = 12.59$$
$$O = 2x + z + u + 3\times0.45 = 21.41$$
$$H = 2y + 2u = 3.54$$

From these relations

$$y = x - 5.70$$
$$z = 12.59 - x$$
$$u = 7.47 - x$$

*(e) Calculation of Characteristic Values*

From the heat of formation,

$$Q_1 = xq_{CO_2} + zq_{CO} + uq_{(H_2O)} + 0.45q_{SO_3} + 4.91q_{KCl} - q + \Delta q$$

The relation of the equilibrium constant and the temperature comes from Table 9.

First the author obtained $T_v$ = 3900 K and using the corresponding value of $K(T)$ = 8.36, a precise calculation was carried out.

$$K(T) = \frac{z \cdot u}{x \cdot y} = \frac{(12.59 - x)(7.47 - x)}{x(x - 5.70)} = 8.36$$

From this equation we have $x$ = 5.91, and then we have

$$y = 5.91 - 4.80 = 1.11$$
$$z = 12.59 - 5.91 = 6.68$$
$$u = 6.57 - 5.91 = 0.66$$

On the other hand,

$$q_{CO_2} = 97.80 \text{ kcal}$$
$$q_{SO_3} = 91.9 \text{ kcal}$$
$$q_{CO} = 29.7 \text{ kcal}$$
$$q_{[KCl]} = 105.6 \text{ kcal}$$
$$q_{(H_2O)} = 68.31 \text{ kcal}$$

$$q = 4.91q_{[KClO_4]} + 1.27q_{(H_2O)} + 0.10q_{[C_6H_{10}O_5]}$$
$$= 4.91 \times 113.5 + 1.27 \times 68.31 + 0.10 \times 226.8$$
$$= 666.72 \text{ kcal}$$

$$\Delta q = 0.57 \times \begin{pmatrix} x + y + z + u + \\ 0.45 + 1.62 + 4.91 \end{pmatrix}$$
$$= 0.57 \times \begin{pmatrix} 5.91 + 1.11 + 6.68 + \\ 0.66 + 0.45 + 1.62 + 4.91 \end{pmatrix}$$
$$= 12.16 \text{ kcal}$$

Therefore the value of $Q_1$ is:

$$Q_1 = 5.91 \times 97.80 + 6.68 + 24.70 + 0.66 \times 68.31 + 0.45 \times 91.9 + 4.91 \times 105.6 - 666.72 + 12.16$$
$$= 726.78 \text{ kcal}$$

From the internal energy of the component materials, we have:

$$Q_2 = xE_{CO_2}(T) + yE_{H_2}(T) + zE_{CO}(T) + uE_{H_2O}(T) + 0.45E_{SO_3}(T) + 1.62E_{S_2}(T) + 4.91E_{KCl}(T)$$

From Table 6 the value of $Q_2$ was calculated for temperatures from 3000 to 4000 K. The case of $E_{H_2O}$ was considered from the liquid state, and the value of the latent heat of evaporation of water 10.54 kcal/mole (20 °C) was added:

| T (K) | $x\,E_{CO_2}$ (T) | $y\,E_{H_2}$ (T) | $z\,E_{CO}$ (T) | $u\,E_{H_2O}$ (T) | 0.45 $E_{SO_3}$ (T) | 1.62 $E_{S_2}$ (T) | 4.91 $E_{KCl}$ (T) |
|---|---|---|---|---|---|---|---|
| 3000 | 187.52 | 17.77 | 117.63 | 23.70 | 18.88 | 42.54 | 142.10 |
| 3500 | 224.99 | 21.36 | 140.35 | 27.36 | 22.64 | 50.27 | 156.73 |
| 4000 | 262.64 | 25.00 | 163.26 | 31.07 | 26.25 | 58.14 | 171.36 |

Therefore:

| T (K) | $Q_2$ (kcal) |
|---|---|
| 3000 | 550.14 |
| 3500 | 643.70 |
| 4000 | 737.72 |

A graph of $T$ vs $Q_2$ was drawn and on the curve of $T$ vs $Q_2$ the point corresponding to $Q_2$ = 727 showed the explosive temperature: $T_v$ = 3940 K.

The specific volume is calculated as:

$$\bar{V}_o = (x + y + z + u + 0.45 + 1.62 + 4.91) \times 22.41$$
$$= \begin{pmatrix} 5.91 + 1.11 + 6.68 + \\ 0.66 + 0.45 + 1.62 + 4.91 \end{pmatrix} \times 22.41$$
$$= 478 \text{ liter}$$

The force of explosive is calculated as:

$$f_P = 0.3782\bar{V}_o T_v = 0.3782 \times 478 \times 3940$$
$$= 0.712 \times 10^6 \text{ dm}$$

*4. The Characteristic Values of Black Powder* (**S**)

*(a) The Composition of 1 kg Mixture:*

| Materials | Mixing Ratio (%) | Quantity in 1 kg of Mixture (g) | Chemical Constituents | Composition (%) | Quantity in 1 kg Mixture (g) |
|---|---|---|---|---|---|
| Potassium nitrate | 75 | 735 | $KNO_3$ | 100 | 735 |
| Hemp charcoal | 15 | 147 | C | 82.0 | 120 |
| | | | $H_2O$ | 10.0 | 15 |
| | | | Ash | 8.0 | 12 |
| Sulfur | 10 | 98 | $S_2$ | 100.0 | 98 |
| Glutinous rice starch | 2 | 20 | $C_6H_{10}O_5$ | 87.0 | 17 |
| | | | $H_2O$ | 13.0 | 3 |
| | 102 | 1000 | | | 1000 |

*(b) Number of Moles in 1 kg Mixture*

$$
\begin{aligned}
KNO_3 &= 735 / 101.10 &= 7.27 \text{ mole}\\
C &= 120 / 12.01 &= 9.99 \text{ mole}\\
S_2 &= 98/64.12 &= 1.53 \text{ mole}\\
H_2O &= 18 / 18.02 &= 1.00 \text{ mole}\\
C_6H_{10}O_5 &= 17 / 162.16 &= 0.10 \text{ mole}
\end{aligned}
$$

*(c) Number of Gram Atoms in 1 kg Mixture*

| | K | N | O | C | H | S |
|---|---|---|---|---|---|---|
| $KNO_3$ | 7.27 | 7.27 | 21.81 | — | — | — |
| C | — | — | — | 9.99 | — | — |
| $S_2$ | — | — | — | — | — | 3.06 |
| $H_2O$ | — | — | 1.00 | — | 2.00 | — |
| $C_6H_{10}O_5$ | — | — | 0.50 | 0.60 | 1.00 | — |
| | 7.27 | 7.27 | 23.31 | 10.59 | 3.00 | 3.06 |

*(d) Explosive Reaction*

As a hypothesis, it is proposed that the steps in the explosive reaction are as follows: [The number under the chemical formula shows the moles of the substance.]

**Reaction (1)**

$$
\begin{array}{ccccccccc}
2\,KNO_3 & + & \tfrac{1}{2}\,S_2 & = & K_2SO_4 & + & N_2 & + & O_2\\
6.12 & & 1.53 & & 3.06 & & 3.06 & & 3.06
\end{array}
$$

The remaining $KNO_3$ is

$7.27 - 6.12 = 1.15$ mole

**Reaction (2)**

$$
\begin{array}{ccccccccc}
2\,KNO_3 & + & C & = & K_2CO_3 & + & N_2 & + & 3/2\,O_2\\
1.15 & & 0.58 & & 0.58 & & 0.58 & & 0.87
\end{array}
$$

The remaining C is

$10.59 - 0.58 = 10.01$ mole

The remaining $O_2$ is

$3.06 + 0.87 = 3.93$ mole

**Reaction (3)**

$$
\begin{array}{ccccc}
C & + & O_2 & = & CO_2\\
3.93 & & 3.93 & & 3.93
\end{array}
$$

The remaining C is

$10.01 - 3.93 = 6.08$ mole

**Reaction (4)**

$$
\begin{array}{ccccccccccc}
K_2SO_4 & + & 7/4\,C & = & \tfrac{1}{2}\,K_2CO_3 & + & \tfrac{1}{2}\,K_2S & + & \tfrac{1}{4}\,S_2 & + & \tfrac{1}{4}\,CO_2\\
3.06 & & 5.36 & & 1.53 & & 1.53 & & 0.77 & & 3.83
\end{array}
$$

The remaining C is

$6.08 - 5.36 = 0.72$ mole

The remaining $CO_2$ is

$3.93 + 3.83 = 7.76$ mole

**Reaction (5)**

$$
\begin{array}{ccccc}
CO_2 & + & C & = & 2\,CO\\
0.72 & & 0.72 & & 1.44
\end{array}
$$

Thus the carbon is totally consumed.

The $K_2CO_3$ remaining is

$0.58 + 1.53 = 2.11$ mole

**Reaction (6)**

$K_2CO_3$ dissociates at high temperatures:

$$K_2CO_3 = K_2O + CO_2$$
$$2.11 \quad 2.11 \quad 2.11$$

From the above reactions, 7.27 mol $N_2$, 2.11 mol $K_2O$, 1.53 mol $K_2S$, 0.77 mol $S_2$ and other gases $CO_2$ and CO are produced. In this case there may also be the water gas reaction, which produces $H_2$ gas. Therefore, in consideration of this reaction, we have:

$$\text{1 kg of mixture} = x\,CO_2 + y\,H_2 + z\,CO + u\,H_2O + 3.64\,N_2 + 0.77\,S_2 + 2.11\,K_2O + 1.53\,K_2S + Q$$

From the number of atoms

$$C = x + z = 10.59$$
$$O = 2x + z + u + 2.11 = 23.31$$
$$H = 2y + 2u = 3.00$$

From these relations

$$y = x - 9.11$$
$$z = 10.59 - x$$
$$u = 10.61 - x$$

*(e) Calculation of Characteristic Values*

The reaction heat is obtained by the relation of the heat of formations:

$$Q_1 = xq_{CO_2} + zq_{CO} + uq_{(H_2O)} + 2.11q_{[K_2O]} + 1.53q_{[K_2S]} - q + \Delta q$$

From a rough calculation of explosion temperature, $T_v$ = 2000 K was obtained. Therefore from Table 9 the equilibrium constant $K(T)$ = 4.46 was obtained. Therefore,

$$K(T) = \frac{z \cdot u}{x \cdot y} = \frac{(10.59 - x)(10.61 - x)}{x(x - 9.11)} = 4.46$$

From this equation we have

$$x = 9.16.$$

Further we obtained

$$y = 9.16 - 9.11 = 0.05$$
$$z = 10.59 - 9.16 = 1.43$$
$$u = 10.61 - 9.16 = 1.45$$

We also have:

$$q_{[K_2O]} = 86.8 \text{ kcal}$$
$$q_{[K_2S]} = 87.3 \text{ kcal}$$
$$q = 7.27q_{[KNO_3]} + 1.00q_{(H_2O)} + 0.10q_{[C_6H_{10}O_5]}$$
$$= 7.27 \times 119.5 + 1.00 \times 68.31 + 0.10 \times 226.8$$
$$= 959.75 \text{ kcal}$$
$$\Delta q = 0.57 \times (x + y + z + u + 3.64 + 0.77)$$
$$= 0.57 \times \begin{pmatrix} 9.16 + 0.05 + 1.43 + \\ 1.45 + 3.64 + 0.77 \end{pmatrix}$$
$$= 9.41 \text{ kcal}$$

Therefore the value of $Q_1$ is obtained:

$$Q_1 = 9.16 \times 97.80 + 1.43 \times 29.70 + 1.45 \times 68.31 + 2.11 \times 86.8 + 1.53 \times 87.3 - 959.75 + 9.41$$
$$= 403.75$$

From the internal energy of each product:

$$Q_2 = xE_{CO_2}(T) + yE_{H_2}(T) + zE_{CO}(T) + uE_{H_2O}(T) + 3.64E_{N_2}(T) + 0.77E_{S_2}(T) + 2.11E_{[K_2O]}(T) + 1.53E_{[K_2S]}(T)$$

From of values of $Q_2$ are calculated from Tables 6 and 8: [For $E_{H_2O}$ the latent heat of evaporation (10.54 kcal/mol at 20 °C) is added.]

| T (K) | $x\,E_{CO_2}$ (T) | $y\,E_{H_2}$ (T) | $z\,E_{CO}$ (T) | $u\,E_{H_2O}$ (T) | 3.64 $E_{N_2}$ (T) | 0.77 $E_{S_2}$ (T) |
|---|---|---|---|---|---|---|
| 1500 | 120.73 | 0.35 | 10.93 | 29.77 | 27.45 | 9.53 |
| 2000 | 176.24 | 0.49 | 15.57 | 36.76 | 39.13 | 13.04 |
| 2500 | 233.12 | 0.64 | 20.35 | 44.25 | 51.21 | 16.60 |

| T (K) | 2.11 $E_{[K_2O]}$ (T) | 1.53 $E_{[K_2S]}$ (T) | $Q_2$ (kcal) |
|---|---|---|---|
| 1500 | 45.70 | 33.14 | 277.60 |
| 2000 | 64.54 | 46.80 | 392.57 |
| 2500 | 83.41 | 60.48 | 510.06 |

A graph of $T$ vs $Q_2$ is then drawn and the temperature at $Q_1$ = 404 kcal is read. This is the temperature of the explosion ($T_v$).

$T_v$ = 2050 K.

The specific volume is:

$$
\begin{aligned}
\overline{V}_o &= (x+y+z+u+3.64+0.77)\times 22.41 \\
&= \begin{pmatrix} 9.16+0.05+1.43+ \\ 1.45+3.64+0.77 \end{pmatrix} \times 22.41 \\
&= 370 \text{ liter}
\end{aligned}
$$

The force of explosives $f_s$ is

$$
\begin{aligned}
f_s &= 0.3782\overline{V}_o T_v = 0.3782\times 370\times 2050 \\
&= 0.287\times 10^6 \text{ dm}
\end{aligned}
$$

### 4.3.3 Fuse, Shells and Pasting

For the main fuse, industrial fuse of the second class was used. The shell was made of newspaper, which is the most rational choice because the breaking strength of newspaper is almost negligible. The internal diameter was 105 mm, with a thickness of 2.5 mm. This is called four sun. Another shell called five sun had an internal diameter of 132 mm with a thickness of 3.0 mm.

For the types of paper used in pasting the shells, the following symbols are used:

| Japanese paper | Kraft paper |
| --- | --- |
| $\mathbf{W}_{16}$ | $\mathbf{M}_8$ |
| $\mathbf{W}_8$ | $\mathbf{M}_4$ |

where **W** means Japanese paper and **M** means Kraft paper. The subscripts show the number of pasting layers of paper per a diameter length of sun (1.2 inches). For example, with the symbol $\mathbf{W}_{16}$ for 5 inch shell (4 sun shell), the number of pasting layers should be $16 \times 5 = 80$. Figure 14 (A) shows the layers of $\mathbf{W}_8$ and (B) shows the layers of $\mathbf{W}_{16}$ for 5 sun (6 inch) shells.

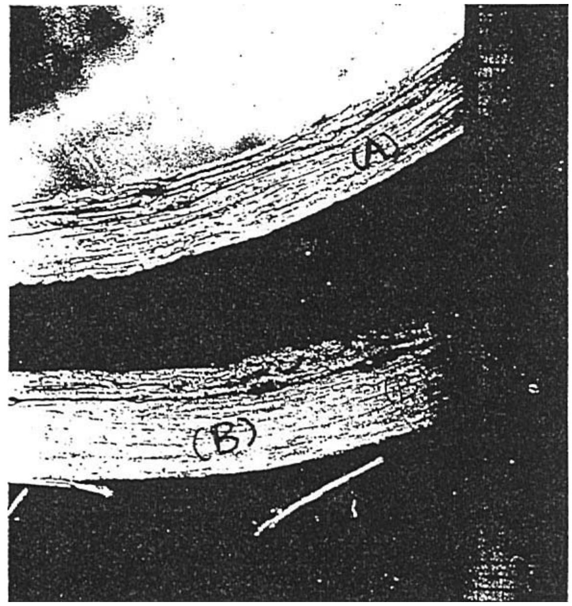



*Figure 14. Sections of pasted shell.*

In this case sample shells were pasted with two-folded Japanese paper and unfolded Kraft paper. The total sum of the actual paper sheet area divided by the theoretical value $S_o$ was 1.08 for Japanese paper and 1.17 for Kraft paper.

The wheat paste used for preparing the two-folded Japanese paper was wheat starch and water in the ration 1:10. The paste used for pasting paper onto the shell was wheat starch and water in the ratio 1:3.

The strength of the paper was measured experimentally. The test pieces were made as for tests of metal tensile strength. The strip was 20 mm wide. The sample consisted of no fold, 2 folds, 5 folds and 10 folds of paper and the tensile strengths were measured. The humidity was 77% and the air temperature was 16.5 °C.

**Table 10. Breaking Strength of Paper.**

| Paper Type | Number of Folds | Fiber Direction | Thickness (mm) | Breaking Weight (kg) | Tensile Strength ($kg/cm^2$) |
|---|---|---|---|---|---|
| Japanese paper *gundo* M.C. = 8.8% | 1 | — | 0.08 | 2.4 | 150 |
| | 1 | \| | 0.08 | 4.3 | 269 |
| | 5 | \| | 0.45 | 19.1 | 212 |
| | 10 | \| | 0.96 | 53.2 | 277 |
| | 2 | + | 0.16 | 7.3 | 228 |
| | 10 | + | 0.96 | 47.3 | 246 |
| Kraft paper (Cement bag) M.C. = 10.6% | 1 | — | 0.14 | 3.9 | 140 |
| | 1 | \| | 0.14 | 8.1 | 289 |
| | 5 | \| | 0.72 | 37.4 | 267 |
| | 2 | + | 0.28 | 12.0 | 214 |
| Newspaper M.C. = 10.9% | 1 | — | 0.12 | 0.8 | 33 |
| | 1 | \| | 0.12 | 1.7 | 71 |
| | 2 | \| | 0.26 | 4.2 | 81 |
| | 5 | + | 0.67 | 6.8 | 51 |
| | 10 | + | 1.48 | 16.4 | 55 |

M.C. = moisture content

In Table 10 the symbol (—) indicates that the fibers are arranged at a right angle to the pulling direction, ( | ) indicates that the fibers are parallel to the pulling direction, and (+) indicates that the fibers are folded alternately (parallel and at right angles). The tensile strength of (—) and ( | ) are quite different from each other. The ratio of (—)/( | ) = 0.48 to 0.55. The mixed strength (+) almost equals the sum of (—) and ( | ). The tensile strength of Japanese paper is almost the same as that of Kraft. They show 270–290 $kg/cm^2$ in the direction of the fiber length and 140–150 $kg/cm^2$ at right angle to the fiber. This is very small in comparison of the tensile strength of steel (3500–5000 $kg/cm^2$). The tensile strength of newspaper is 25–35% of Kraft paper and very weak. The Japanese and Kraft papers have almost the same tensile strength. The thickness of the Japanese paper is 0.08 mm and the Kraft is 0.14 mm. Therefore, two sheets of the Japanese paper correspond to one sheet of the Kraft.

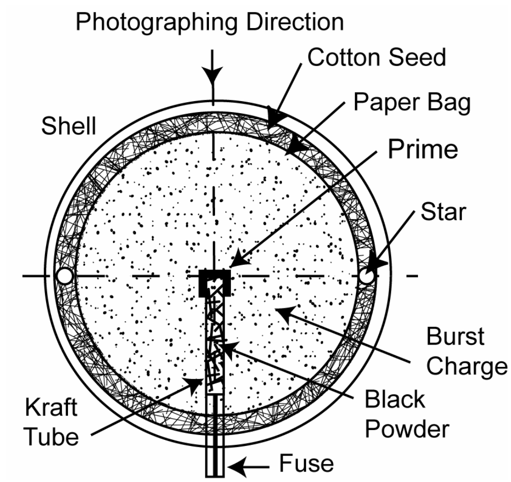
### 4.3.4 Construction of the Sample Shell

As sample shells, we used ring shells to make the analysis easy after the experiment. The construction of the ring shell is shown in Figure 15. The ring shell projects stars in the form of a ring. Cottonseeds were used to fill the space that would normally be occupied by other stars.

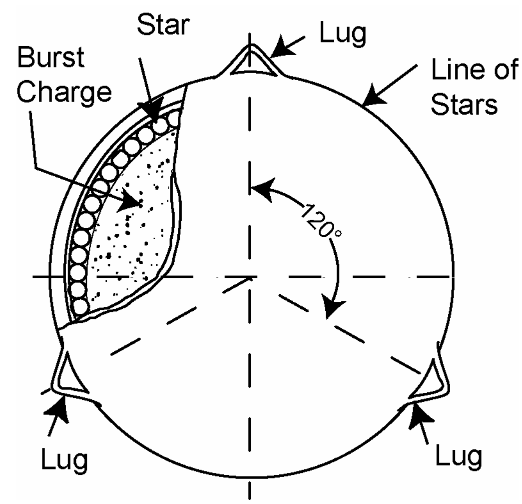
A "Line of Stars" was drawn on the shell case to show the position of the ring. Three lugs were attached to the shell case to allow the shell to be suspended in a fixed orientation with respect to the plane of the star ring, as shown in Figure 20.

The cottonseeds were put into a container, water was poured in to a known volume, and the volume of the cottonseeds was obtained. The true volume of 1 kg cottonseeds is 1.211 liter. Therefore:

$$\Delta = \frac{\varpi}{V - nv_s - 1.211(\varpi' + \varpi'')}$$




(A) Sectional View
(horizontal)




(B) Sectional View
(vertical)

*Figure 15. The construction of the sample ring shell.*

where

| | |
|---|---|
| V | the internal volume of the shell (l) |
| $\varpi$ | the quantity of the burst charge without the binding material (kg) |
| $v_s$ | the volume of a star (l) |
| $n$ | the number of stars |
| $\varpi'$ | the weight of the cottonseeds for the burst charge (kg) |
| $\varpi''$ | the weight of the cottonseeds for packing material (kg) |
| $\Delta$ | the loading density (kg/l) |

The calculated data are shown in Table 11.

### 4.3.5 Table of Sample Shells

The sample stars manufactured by the above method are arranged in Table 11. The symbols used in the table are as follows. For example, $D_4B_8\mathbf{HW}_8$ means

| | |
|---|---|
| $D_4$ | 4 sun shell (5 inch shell) |
| $B_8$ | 8 mm blue star |
| **H** | Burst charge: *haisan* (potassium chlorate burst charge) |
| $\mathbf{W}_8$ | Japanese paper *sunto* 8x4 folds pasting. |

Shells 1 to 48, which all contained blue stars, were used to determine the effect of the movement on stars of: the size of the shell, the size of the stars, the type of burst charge, the kind of paper pasted, and the number of pasted layers of paper.

Shells 49 to 56 were used to determine the effect of velocity on the star. Specifically, shells 49 to 53 contained three types of stars in the same shell, and were used to compare the velocity of stars without the effect of manufacturing deviations. Shells 57 to 60 were so called *manboshi* (ordinary chrysanthemum), in which the shells were filled with stars. This was for comparison with the ring shells. Shells 61 and 62 were commercial shells that were compared with the test sample shells.

**Table 11. Sample Shells.**

| Shell Test No. | Symbol | Nom. Shell Dia. | Star | | | | Burst Charge | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Color | Dia. (mm) | No. Stars | Form | Type | Quant. (kg) | Net Wt. (kg) | Cottonseeds B. Chg. (kg) |
| 1 | $D_4B_8\mathbf{HW}_8$ | 4 sun | blue | 8 | 35 | Ring | | | | |
| 2 | $D_4B_8\mathbf{HW}_{16}$ | (5 in.) | blue | 8 | 34 | Ring | | | | |
| 3 | $D_4B_8\mathbf{HM}_4$ | \| | blue | 8 | 35 | Ring | **H** | 0.188 | 0.107 | 0.081 |
| 4 | $D_4B_8\mathbf{HM}_8$ | \| | blue | 8 | 35 | Ring | **H** | 0.188 | 0.107 | 0.081 |
| 5 | $D_4B_8\mathbf{SW}_8$ | \| | blue | 8 | 33 | Ring | **S** | 0.188 | 0.106 | 0.082 |
| 6 | $D_4B_8\mathbf{SW}_{16}$ | \| | blue | 8 | 34 | Ring | **S** | 0.188 | 0.106 | 0.082 |
| 7 | $D_4B_8\mathbf{SM}_4$ | \| | blue | 8 | 34 | Ring | **S** | 0.188 | 0.106 | 0.082 |
| 8 | $D_4B_8\mathbf{SM}_8$ | \| | blue | 8 | 34 | Ring | **S** | 0.188 | 0.106 | 0.082 |
| 9 | $D_4B_8\mathbf{PW}_8$ | \| | blue | 8 | 34 | Ring | **P** | 0.188 | 0.116 | 0.072 |
| 10 | $D_4B_8\mathbf{PW}_{16}$ | \| | blue | 8 | 34 | Ring | **P** | 0.188 | 0.116 | 0.072 |
| 11 | $D_4B_8\mathbf{PM}_4$ | \| | blue | 8 | 35 | Ring | **P** | 0.188 | 0.116 | 0.072 |
| 12 | $D_4B_8\mathbf{PM}_8$ | \| | blue | 8 | 34 | Ring | **P** | 0.188 | 0.116 | 0.072 |
| 13 | $D_4B_{12}\mathbf{HW}_8$ | \| | blue | 12 | 24 | Ring | **H** | 0.188 | 0.107 | 0.081 |
| 14 | $D_4B_{12}\mathbf{HW}_{16}$ | \| | blue | 12 | 24 | Ring | **H** | 0.188 | 0.107 | 0.081 |
| 15 | $D_4B_{12}\mathbf{HM}_4$ | \| | blue | 12 | 24 | Ring | **H** | 0.188 | 0.107 | 0.081 |
| 16 | $D_4B_{12}\mathbf{HM}_8$ | \| | blue | 12 | 24 | Ring | **H** | 0.188 | 0.107 | 0.081 |
| 17 | $D_4B_{12}\mathbf{SW}_8$ | \| | blue | 12 | 24 | Ring | **S** | 0.188 | 0.106 | 0.082 |
| 18 | $D_4B_{12}\mathbf{SW}_{16}$ | \| | blue | 12 | 23 | Ring | **S** | 0.188 | 0.106 | 0.082 |
| 19 | $D_4B_{12}\mathbf{SM}_4$ | \| | blue | 12 | 24 | Ring | **S** | 0.188 | 0.106 | 0.082 |
| 20 | $D_4B_{12}\mathbf{SM}_8$ | \| | blue | 12 | 24 | Ring | **S** | 0.188 | 0.106 | 0.082 |
| 21 | $D_4B_{12}\mathbf{PW}_8$ | \| | blue | 12 | 24 | Ring | **P** | 0.188 | 0.116 | 0.072 |
| 22 | $D_4B_{12}\mathbf{PW}_{16}$ | \| | blue | 12 | 24 | Ring | **P** | 0.188 | 0.116 | 0.072 |
| 23 | $D_4B_{12}\mathbf{PM}_4$ | \| | blue | 12 | 24 | Ring | **P** | 0.188 | 0.116 | 0.072 |
| 24 | $D_4B_{12}\mathbf{PM}_8$ | ↓ | blue | 12 | 24 | Ring | **P** | 0.188 | 0.116 | 0.072 |
| 25 | $D_5B_8\mathbf{HW}_8$ | 5 sun | blue | 8 | 45 | Ring | **H** | 0.413 | 0.234 | 0.179 |
| 26 | $D_5B_8\mathbf{HW}_{16}$ | (6 in.) | blue | 8 | 45 | Ring | **H** | 0.413 | 0.234 | 0.179 |
| 27 | $D_5B_8\mathbf{HM}_4$ | \| | blue | 8 | 45 | Ring | **H** | 0.413 | 0.234 | 0.179 |
| 28 | $D_5B_8\mathbf{HM}_8$ | \| | blue | 8 | 45 | Ring | **H** | 0.413 | 0.234 | 0.179 |
| 29 | $D_5B_8\mathbf{SW}_8$ | \| | blue | 8 | 44 | Ring | **S** | 0.413 | 0.232 | 0.181 |
| 30 | $D_5B_8\mathbf{SW}_{16}$ | \| | blue | 8 | 44 | Ring | **S** | 0.413 | 0.232 | 0.181 |
| 31 | $D_5B_8\mathbf{SM}_4$ | \| | blue | 8 | 44 | Ring | **S** | 0.413 | 0.232 | 0.181 |
| 32 | $D_5B_8\mathbf{SM}_8$ | \| | blue | 8 | 44 | Ring | **S** | 0.413 | 0.232 | 0.181 |
| 33 | $D_5B_8\mathbf{PW}_8$ | \| | blue | 8 | 44 | Ring | **P** | 0.413 | 0.256 | 0.157 |
| 34 | $D_5B_8\mathbf{PW}_{16}$ | \| | blue | 8 | 44 | Ring | **P** | 0.413 | 0.256 | 0.157 |
| 35 | $D_5B_8\mathbf{PM}_4$ | \| | blue | 8 | 44 | Ring | **P** | 0.413 | 0.256 | 0.157 |
| 36 | $D_5B_8\mathbf{PM}_8$ | \| | blue | 8 | 45 | Ring | **P** | 0.413 | 0.256 | 0.157 |

**Table 11. Sample Shells. (Continued)**

| Shell Test No. | Symbol | Cottonseed Filling (kg) | Loading Density of Burst Charge (kg/l) | Paper Pasting | | | |
|---|---|---|---|---|---|---|---|
| | | | | Type of Paper | No. of folds | da-di (mm) | Total Wt. (kg) |
| | | | | Washi | 8 | 5.7 | 0.480 |
| 2 | $D_4B_8\mathbf{HW}_{16}$ | 0.118 | 0.276 | Washi | 16 | 10.0 | 0.565 |
| 3 | $D_4B_8\mathbf{HM}_4$ | 0.116 | 0.274 | Kraft | 4 | 5.0 | 0.490 |
| 4 | $D_4B_8\mathbf{HM}_8$ | 0.120 | 0.277 | Kraft | 8 | 8.0 | 0.565 |
| 5 | $D_4B_8\mathbf{SW}_8$ | 0.117 | 0.273 | Washi | 8 | 5.3 | 0.480 |
| 6 | $D_4B_8\mathbf{SW}_{16}$ | 0.137 | 0.291 | Washi | 16 | 11.0 | 0.600 |
| 7 | $D_4B_8\mathbf{SM}_4$ | 0.135 | 0.289 | Kraft | 4 | 5.0 | 0.500 |
| 8 | $D_4B_8\mathbf{SM}_8$ | 0.140 | 0.295 | Kraft | 8 | 10.0 | 0.575 |
| 9 | $D_4B_8\mathbf{PW}_8$ | 0.121 | 0.293 | Washi | 8 | 5.2 | 0.480 |
| 10 | $D_4B_8\mathbf{PW}_{16}$ | 0.129 | 0.301 | Washi | 16 | 13.0 | 0.610 |
| 11 | $D_4B_8\mathbf{PM}_4$ | 0.120 | 0.292 | Kraft | 4 | 5.0 | 0.472 |
| 12 | $D_4B_8\mathbf{PM}_8$ | 0.124 | 0.296 | Kraft | 8 | 10.0 | 0.572 |
| 13 | $D_4B_{12}\mathbf{HW}_8$ | 0.122 | 0.287 | Washi | 8 | 4.1 | 0.480 |
| 14 | $D_4B_{12}\mathbf{HW}_{16}$ | 0.120 | 0.285 | Washi | 16 | 8.0 | 0.520 |
| 15 | $D_4B_{12}\mathbf{HM}_4$ | 0.120 | 0.285 | Kraft | 4 | 5.0 | 0.492 |
| 16 | $D_4B_{12}\mathbf{HM}_8$ | 0.122 | 0.287 | Kraft | 8 | 8.1 | 0.530 |
| 17 | $D_4B_{12}\mathbf{SW}_8$ | 0.128 | 0.290 | Washi | 8 | 8.0 | 0.525 |
| 18 | $D_4B_{12}\mathbf{SW}_{16}$ | 0.119 | 0.281 | Washi | 16 | 10.0 | 0.585 |
| 19 | $D_4B_{12}\mathbf{SM}_4$ | 0.119 | 0.282 | Kraft | 4 | 9.0 | 0.505 |
| 20 | $D_4B_{12}\mathbf{SM}_8$ | 0.113 | 0.277 | Kraft | 8 | 10.0 | 0.563 |
| 21 | $D_4B_{12}\mathbf{PW}_8$ | 0.114 | 0.294 | Washi | 8 | 6.7 | 0.495 |
| 22 | $D_4B_{12}\mathbf{PW}_{16}$ | 0.126 | 0.306 | Washi | 16 | 11.7 | 0.580 |
| 23 | $D_4B_{12}\mathbf{PM}_4$ | 0.114 | 0.294 | Kraft | 4 | 3.2 | 0.495 |
| 24 | $D_4B_{12}\mathbf{PM}_8$ | 0.122 | 0.302 | Kraft | 8 | 8.0 | 0.565 |
| 25 | $D_5B_8\mathbf{HW}_8$ | 0.225 | 0.299 | Washi | 8 | 8.0 | 0.955 |
| 26 | $D_5B_8\mathbf{HW}_{16}$ | 0.221 | 0.297 | Washi | 16 | 12.0 | 1.100 |
| 27 | $D_5B_8\mathbf{HM}_4$ | 0.206 | 0.290 | Kraft | 4 | 4.1 | 0.905 |
| 28 | $D_5B_8\mathbf{HM}_8$ | 0.218 | 0.296 | Kraft | 8 | 6.7 | 0.985 |
| 29 | $D_5B_8\mathbf{SW}_8$ | 0.221 | 0.295 | Washi | 8 | 6.7 | 0.940 |
| 30 | $D_5B_8\mathbf{SW}_{16}$ | 0.194 | 0.283 | Washi | 16 | 15.0 | 1.165 |
| 31 | $D_5B_8\mathbf{SM}_4$ | 0.216 | 0.293 | Kraft | 4 | 7.2 | 0.955 |
| 32 | $D_5B_8\mathbf{SM}_8$ | 0.253 | 0.310 | Kraft | 8 | 11.0 | 1.080 |
| 33 | $D_5B_8\mathbf{PW}_8$ | 0.234 | 0.320 | Washi | 8 | 5.0 | 0.950 |
| 34 | $D_5B_8\mathbf{PW}_{16}$ | 0.208 | 0.308 | Washi | 16 | 13.0 | 1.125 |
| 35 | $D_5B_8\mathbf{PM}_4$ | 0.218 | 0.313 | Kraft | 4 | 6.5 | 0.940 |
| 36 | $D_5B_8\mathbf{PM}_8$ | 0.223 | 0.315 | Kraft | 8 | 10.0 | 1.095 |

**Table 11. Sample Shells. (Continued)**

| Shell Test No. | Symbol | Nom. Shell Dia. | Star | | | | Burst Charge | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Color | Dia. (mm) | No. Stars | Form | Type | Quant. (kg) | Net Wt. (kg) | Cottonseeds B. Chg. (kg) |
| 37 | $D_5B_{12}\mathbf{HW}_8$ | │ | blue | 12 | 31 | Ring | **H** | 0.413 | 0.234 | 0.179 |
| 38 | $D_5B_{12}\mathbf{HW}_{16}$ | │ | blue | 12 | 31 | Ring | **H** | 0.413 | 0.234 | 0.179 |
| 39 | $D_5B_{12}\mathbf{HM}_4$ | │ | blue | 12 | 31 | Ring | **H** | 0.413 | 0.234 | 0.179 |
| 40 | $D_5B_{12}\mathbf{HM}_8$ | │ | blue | 12 | 31 | Ring | **H** | 0.413 | 0.234 | 0.179 |
| 41 | $D_5B_{12}\mathbf{SW}_8$ | │ | blue | 12 | 31 | Ring | **S** | 0.413 | 0.232 | 0.181 |
| 42 | $D_5B_{12}\mathbf{SW}_{16}$ | │ | blue | 12 | 31 | Ring | **S** | 0.413 | 0.232 | 0.181 |
| 43 | $D_5B_{12}\mathbf{SM}_4$ | │ | blue | 12 | 31 | Ring | **S** | 0.413 | 0.232 | 0.181 |
| 44 | $D_5B_{12}\mathbf{SM}_8$ | │ | blue | 12 | 31 | Ring | **S** | 0.413 | 0.232 | 0.181 |
| 45 | $D_5B_{12}\mathbf{PW}_8$ | │ | blue | 12 | 31 | Ring | **P** | 0.413 | 0.256 | 0.157 |
| 46 | $D_5B_{12}\mathbf{PW}_{16}$ | │ | blue | 12 | 31 | Ring | **P** | 0.413 | 0.256 | 0.157 |
| 47 | $D_5B_{12}\mathbf{PM}_4$ | │ | blue | 12 | 31 | Ring | **P** | 0.413 | 0.256 | 0.157 |
| 48 | $D_5B_{12}\mathbf{PM}_8$ | │ | blue | 12 | 31 | Ring | **P** | 0.413 | 0.256 | 0.157 |
| 49 | $D_5C_{12}G_{12}B_{12}\mathbf{SW}_8$ | │ | — | 12 | 30 | Ring | **S** | 0.413 | 0.232 | 0.181 |
| 50 | $D_5G_{12}\mathbf{SW}_8$ | │ | — | 12 | 30 | Ring | **S** | 0.413 | 0.232 | 0.181 |
| 51 | $D_5C_8\mathbf{SW}_8$ | │ | — | 8 | 45 | Ring | **S** | 0.413 | 0.232 | 0.181 |
| 52 | $D_5C_{12}\mathbf{SW}_8$ | │ | — | 12 | 31 | Ring | **S** | 0.413 | 0.232 | 0.181 |
| 53 | $D_5C_{12}G_{12}B_{12}\mathbf{PW}_8$ | │ | — | 12 | 30 | Ring | **P** | 0.413 | 0.256 | 0.157 |
| 54 | $D_5G_{12}\mathbf{PW}_8$ | │ | — | 12 | 30 | Ring | **P** | 0.413 | 0.256 | 0.157 |
| 55 | $D_5C_8\mathbf{PW}_8$ | │ | — | 8 | 44 | Ring | **P** | 0.413 | 0.256 | 0.157 |
| 56 | $D_5C_{12}\mathbf{PW}_8$ | │ | — | 12 | 31 | Ring | **P** | 0.413 | 0.256 | 0.157 |
| 57 | $D_5B_8\mathbf{SW}_8$ | │ | — | 8 | 660 | Full | **S** | 0.489 | 0.275 | 0.214 |
| 58 | $D_5G_{12}\mathbf{SW}_8$ | ↓ | — | 12 | 315 | Full | **S** | 0.413 | 0.232 | 0.181 |
| 59 | $D_4B_{12}\mathbf{SW}_8$ | 4 sun | — | 12 | 190 | Full | **S** | 0.188 | 0.106 | 0.082 |
| 60 | $D_4B_{12}\mathbf{SW}_8$ | (5 in.) | — | 12 | 190 | Full | **S** | 0.188 | 0.106 | 0.082 |
| 61 | $D_4B_{12}\mathbf{SW}_8$ | 5 sun | — | — | ? | Full | ? | ? | ? | ? |
| 62 | $D_4B_{12}\mathbf{SW}_8$ | (6 in.) | — | — | ? | Full | ? | ? | ? | ? |

Note: Shells 57–60 were chrysanthemum shells, and Shells 61 and 62 were commercial shells.

— means that the color of the stars were not clear.

**Table 11. Sample Shells. (Continued)**

| Shell Test No. | Symbol | Cottonseed Filling (kg) | Loading Density of Burst Charge (kg/l) | Paper Pasting | | | |
|---|---|---|---|---|---|---|---|
| | | | | Type of Paper | No. of folds | da-di (mm) | Total Wt. (kg) |
| 37 | $D_5B_{12}\mathbf{HW}_8$ | 0.216 | 0.300 | Washi | 8 | 5.5 | 0.960 |
| 38 | $D_5B_{12}\mathbf{HW}_{16}$ | 0.208 | 0.296 | Washi | 16 | 12.0 | 1.105 |
| 39 | $D_5B_{12}\mathbf{HM}_4$ | 0.223 | 0.303 | Kraft | 4 | 5.5 | 0.920 |
| 40 | $D_5B_{12}\mathbf{HM}_8$ | 0.212 | 0.298 | Kraft | 8 | 10.0 | 1.105 |
| 41 | $D_5B_{12}\mathbf{SW}_8$ | 0.233 | 0.306 | Washi | 8 | 6.5 | 0.970 |
| 42 | $D_5B_{12}\mathbf{SW}_{16}$ | 0.229 | 0.304 | Washi | 16 | 13.0 | 1.125 |
| 43 | $D_5B_{12}\mathbf{SM}_4$ | 0.221 | 0.300 | Kraft | 4 | 4.5 | 0.950 |
| 44 | $D_5B_{12}\mathbf{SM}_8$ | 0.225 | 0.302 | Kraft | 8 | 10.0 | 1.080 |
| 45 | $D_5B_{12}\mathbf{PW}_8$ | 0.225 | 0.321 | Washi | 8 | 8.5 | 0.985 |
| 46 | $D_5B_{12}\mathbf{PW}_{16}$ | 0.238 | 0.328 | Washi | 16 | 11.5 | 1.100 |
| 47 | $D_5B_{12}\mathbf{PM}_4$ | 0.212 | 0.315 | Kraft | 4 | 6.0 | 0.960 |
| 48 | $D_5B_{12}\mathbf{PM}_8$ | 0.222 | 0.320 | Kraft | 8 | 10.0 | 1.075 |
| 49 | $D_5C_{12}G_{12}B_{12}\mathbf{SW}_8$ | 0.223 | — | Washi | 8 | 6.5 | 0.940 |
| 50 | $D_5G_{12}\mathbf{SW}_8$ | 0.215 | 0.297 | Washi | 8 | 6.5 | 0.960 |
| 51 | $D_5C_8\mathbf{SW}_8$ | 0.230 | — | Washi | 8 | 7.3 | 0.950 |
| 52 | $D_5C_{12}\mathbf{SW}_8$ | 0.188 | — | Washi | 8 | 6.0 | 0.920 |
| 53 | $D_5C_{12}G_{12}B_{12}\mathbf{PW}_8$ | 0.191 | — | Washi | 8 | 6.0 | 0.970 |
| 54 | $D_5G_{12}\mathbf{PW}_8$ | 0.240 | 0.329 | Washi | 8 | 5.5 | 0.950 |
| 55 | $D_5C_8\mathbf{PW}_8$ | 0.227 | — | Washi | 8 | 6.5 | 0.950 |
| 56 | $D_5C_{12}\mathbf{PW}_8$ | 0.227 | — | Washi | 8 | 4.5 | 0.935 |
| 57 | $D_5B_8\mathbf{SW}_8$ | 0.000 | — | Washi | 8 | 7.3 | 1.140 |
| 58 | $D_5G_{12}\mathbf{SW}_8$ | 0.000 | — | Washi | 8 | 6.0 | 1.150 |
| 59 | $D_4B_{12}\mathbf{SW}_8$ | 0.000 | — | Washi | 8 | 6.5 | 0.600 |
| 60 | $D_4B_{12}\mathbf{SW}_8$ | 0.000 | — | Washi | 8 | 5.0 | 0.675 |
| 61 | $D_4X_{12}\mathbf{SW}_8$ | 0.000 | — | Washi | ? | ? | 0.970 |
| 62 | $D_4X_{12}\mathbf{SW}_8$ | 0.000 | — | Washi | ? | ? | 1.240 |

Note: color of stars:

| | | |
|---|---|---|
| Shell 49 | Amber to Green to Blue | CGB |
| Shell 50 | Green | G |
| Shell 51 | Amber | C |
| Shell 52 | Amber | C |
| Shell 53 | Amber to Green to Blue | CGB |
| Shell 54 | Green | G |
| Shell 55 | Amber | C |
| Shell 56 | Amber | C |
| Shell 57 | Blue | B |
| Shell 58 | Green | G |
| Shell 59 | Blue | B |
| Shell 60 | Blue | B |
| Shell 61 | Amber to green to red | X |
| Shell 62 | Double petalled | X |

Shells 61 and 62 were commercial shells.

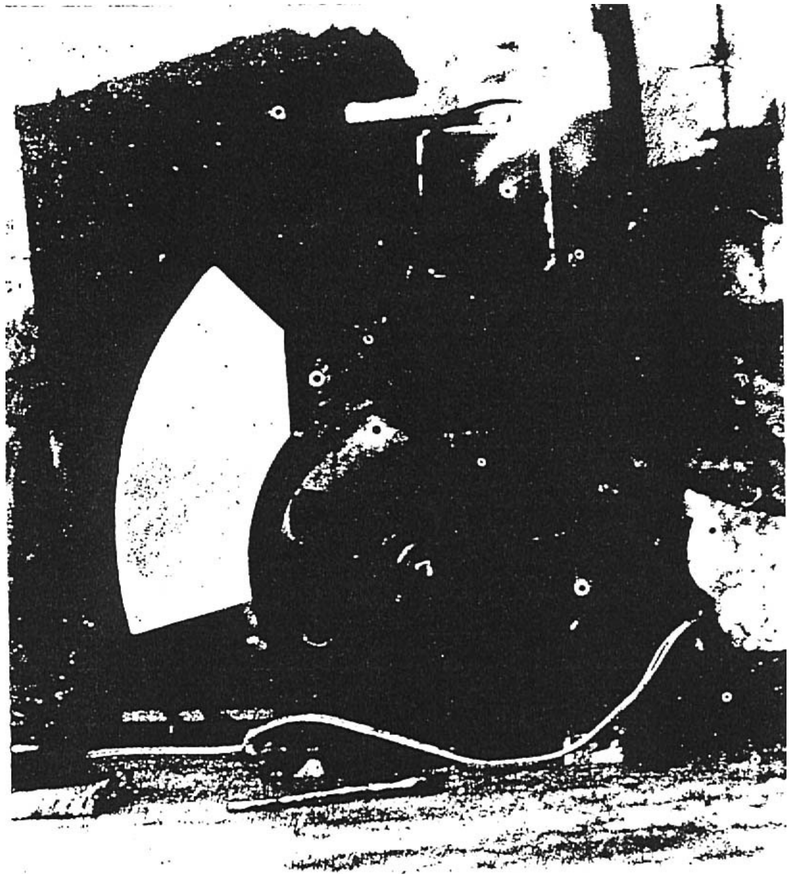


*Figure 16. Revolving shutter.*

## 4.4 Preparation for the Test

### 4.4.1 Main Instruments

***(1) Camera and Accessories:*** Camera (focus: 180 ± 1 mm, f = 4.5) with cabinet-type dry plate.

***(2) Revolving Shutter with a Synchronizing Motor:*** 25 revolutions per second, one wing with shutter angle of 60° (Figure 16).

***(3) 16-mm Movie Camera***: 128 frames per second, 1 inch focus, f = 1.8, 16-mm Kodak film (100 feet) (Figure 17). The record from this camera was used only for reference.

***(4) Illuminators***

***(5) Surveying Instruments***

***(6) A Recorder***

***(7) Distance Poles with Lights***

***(8) Electric Wire for Revolving Shutter***

***(9) Side Camera (not special)***

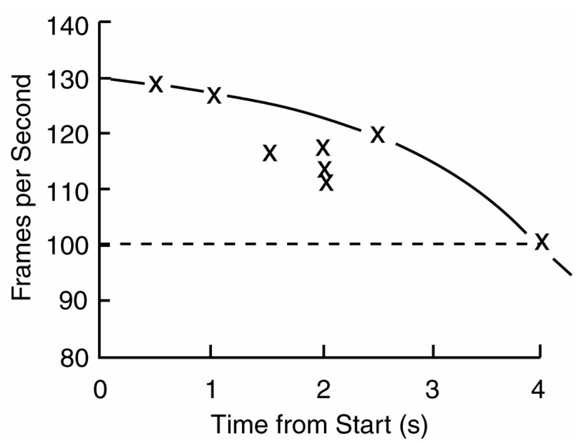



*Figure 17. Number of frames per second as the time passes.*

### 4.4.2 The Arrangement of the Instruments for Burst Charge Experiments

The installation of the test shell is shown in Figures 19 and 20. The plane of the star ring, which was marked on the outside of the test shell (Figure 15, (B)) was placed vertically so that it coincided with the vertical plane including the distance poles with lights (Figure 18). The test shell was held firmly with three pieces of wire 1 meter above the ground (Figures 19 and 20).

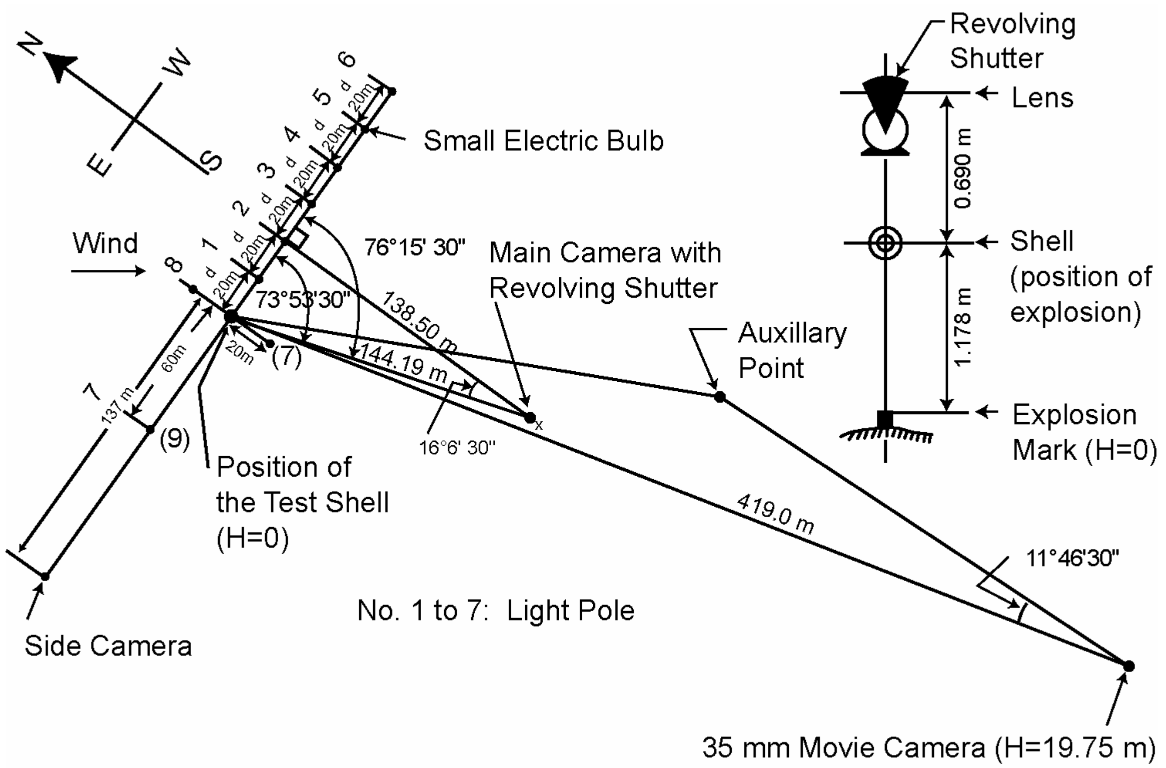



*Figure 18. Arrangement of the instruments for the exploding shells.*

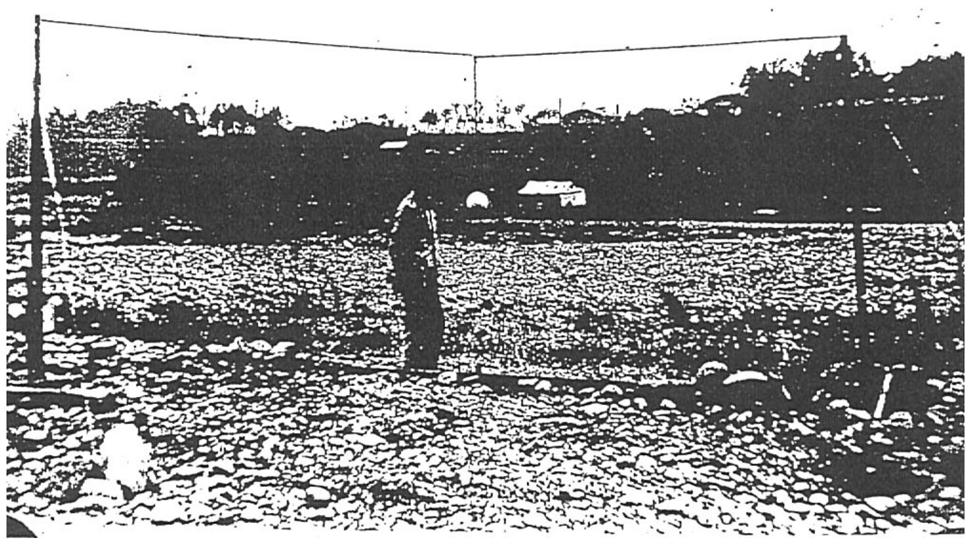


*Figure 19. Installation of the test shell (1 of 2).*

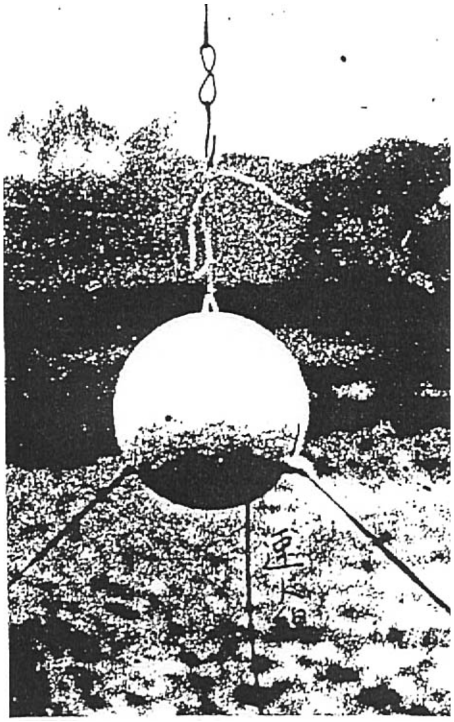


*Figure 20 Installation of the test shell (2 of 2).*

The distance poles with light were set at intervals of 20 meters from the bursting point toward the west (No. 1–6). Another distance pole (No. 7) was set at 60 m from the exploding point toward the east. Two other distance poles were set on either side of the explosion site to the north and south to mark the horizontal line for the side camera. All of the lights on the poles were installed so that they were level with the test shell, which was hung 1 meter above the ground. The distances between the poles (small electric bulbs) were measured with a tape measure that was verified with a 2 m steel tape measure.

The height of the lens of the revolving shutter camera was a little higher (0.64 m) than that of bursting shell. However it was regarded as if they were on a same level. A transit was placed at the No. 2 pole and the axis of the lens of the revolving shutter camera was adjusted so that the axis fell at a right angle to the pole line. Thus these installations could catch the image of about 1/4 of the chrysanthemum.

Small electric bulbs were used for lights on the distance poles for the preliminary test, but from then on candle lights were used to save the electric cells. Only the light on pole No. 2 used both an electric bulb and a candle. However, based on the results, only the candle light was useful.

## 4.5 Progress of the Experiment

**The first day (6 November 1954)**

Preliminary tests were conducted. The test shells were burst on the ground, the bursts were photographed, and the film was developed to confirm the results. Time: 9:30 to 10:00 PM, 0 °C, 100% humidity.

**The second day (7 November 1954)**

Regular tests were conducted. Ignitions with electric devices did not work well and failures occurred with abnormal delay. Then we used black match with good results. Time: 7:15 to l0:l5 PM, 80% humidity. The voltage was too low to power the sound recorder.

**The third day (8th December 1954)**

Time: 6:30 to 11:40 PM, Windy 3–5 m/s, light rain.

**Operations**

The shells bursts were photographed by the camera with the revolving shutter and by the 16-mm movie camera. For confirmation, the side camera was used to show whether or not the stars filled a vertical plane.

The tests were conducted as follows:

- The second day: Shells 1–28
- The third day: Shells 29–60, also Shells 2 and 8, which were left over from the second day.

Photographs for the following tests could not be obtained: Shells 1, 12, 46, and 52.

The photographic results from the l6 mm movie camera were not easy to use because of the deviation of delay times of the ignition of the test shells. However, the following shells were caught almost perfectly by the camera: 22, 28, 33, 34, 36, 37, 40, 42, 43, 44, 45, 47, 49, 52, and 53. These photographs do not have

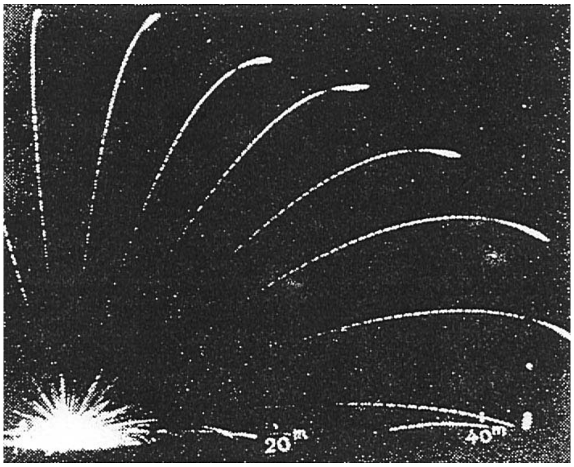



*Figure 21 A. An image taken through the revolving shutter camera from the front.*

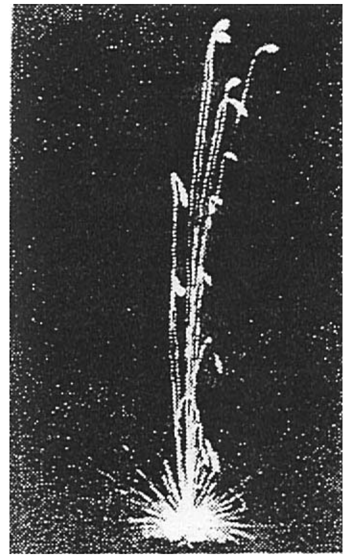


*Figure 21 B. An image from the side.*

enough accuracy to determine the velocity of the stars, but they are useful to explain the way the stars move near the explosion and the way the burst charge burned.

The cycles per second of the electric power that was used for the synchronized motor of the camera, from the report of *Itsukaichi* Power Plant, were as follows:

| December | 8 PM | 11 PM | 15 PM |
|---|---|---|---|
| 6th | 50 | 48.5 | 50 |
| 7th | 50 | 50 | 50 |
| 8th | 48 | 47.5 | 47 |

The following photos show examples of the results obtained from the above experiments. Figure 21 A shows an image taken by the camera with the revolving synchronic shutter. The locus of the stars appears as a series of dotted lines. Figure 21 B shows an image from the side camera, Figure 21 C shows images from the movie camera. All of the photos were taken through an open iris.

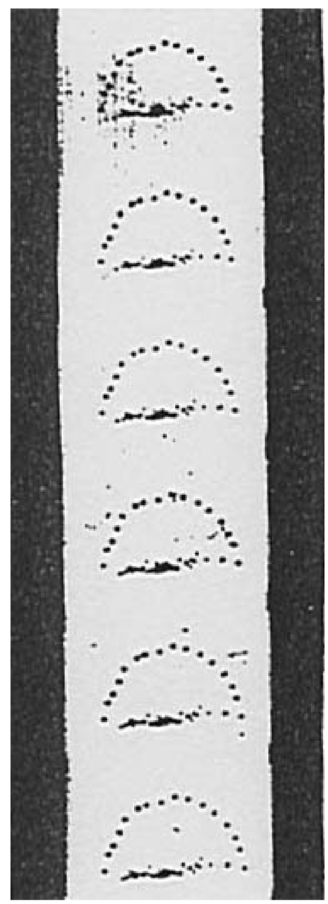


*Figure 21 C. The images taken by the 16-mm movie camera.*