140. *A Physical Investigation on Sparks of "Senkô-hanabi", a Miniature Firework.*

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(Rec. Sept. 30, 1927. Comm. by T. TERADA, M.I.A., Oct. 12, 1927.)

A *senkô-hanabi*,¹⁾ a favourite miniature toy-firework for Japanese childhood, consists of a helical roll of Japanese paper twisted in the same manner as in the strip of insulating paper wound around a wire, containing within the roll about 0.09 gr. of black powder near its head end (Fig. 1). The black powder used is composed of potassium nitrate, sulphur and very fine powder of carbon which is employed as the main constituent of Chinese black.²⁾ When we ignite it at this head end, the powder begins to burn with small vivid flames, and after a few seconds the mass of powder is melted into a small ball with cherry red luminosity. This small fire ball continues to "boil" for about 40 sec. in the molten state, being suspended at the lower end of the paper string, meanwhile emitting intermittently the characteristic sparks called *Matuba*, "leaves of pine-tree." The general view of the sparks is shown in Fig. 2, in which the small circular disc situated near the centre is the said ball. Fig. 3 shows the details of structure of the *Matuba* spark, which was ejected through a slit in order to fall in with the focal plane of the camera.³⁾ The spark ejected from the fire ball travels about 5–10 cm. through the air and then it explodes at a certain point into a number of fine sparklets, which often show the second and third explosions as shown in Fig. 3. These *Matuba* sparks are long in track and few in number in the earlier stage and becomes shorter and more frequent as the phenomenon goes on. Near the end of the

1) Since many years ago, Prof. Terada has been drawing our attention to the effect that the mechanism of formation of sparks of *senkô-hanabi* may form a subject of much interest for physical as well as chemical investigations. Few years ago Dr. Yumoto had initiated some investigations upon this subject.

2) Sometimes, fine powder of iron is added, though it is not the essential constituent. A simple chemical analysis showed that the sample used contains no sensible quantity of iron.

3) The luminosity of spark is very weak and its colour is reddish so that we could obtain well defined photograms only by the use of rapid Panchromatic plate and Cooke lens F/2, which unfortunately has a very shallow focus.

Fig. 1.

Senkô-hanabi. a: the part containing black powder; $\times 0.56$.

Fig. 2.

Sparks of *senkô-hanabi*; $\times 0.4$.

Fig. 3.

Matuba sparks of senkô-hanabi; $\times 0.3$.

Fig. 4.

Sparks of *senkô-hanabi* received on glass plate; $\times 108$.

Fig. 5.

Needle crystals of molten salt; $\times 108$.

display, they tend to assume another typical form of spark called *Tirigiku*, "falling chrysanthemum," or *Yanagi*, "willow," which shows no branching of track but gradual variation of luminosity along the track. This stage lasts about 8 sec. and the fire ball goes out.

The sparks were captured on a glass plate held near the fire ball and the plate was observed under microscope. The mass consisting a spark is composed of an assemblage of very fine particles of carbon—dia. about 5×10^{-5} cm.—imbedded in a transparent matter, probably a molten salt, as shown by the arrows in Fig. 4. This molten mass gradually crystallizes out in a fine needle structure (Fig. 5) which is soluble in water. The crystals change their form when we breath upon them.¹⁾

The temperature of the fire ball was determined by an optical pyrometer. The mean of ten observations showed that the temperature at the beginning of the formation of ball was 856°C. After a few seconds, when it was emitting sparks with great frequency it went up to 935°C. and at the last stage when it ceased to emit sparks the temperature fell to 852°C. again. The rise of temperature will be due to the heat evolved by the oxidation taking place on the surface and also some chemical reaction occurring in the interior of the ball. A simple chemical analysis showed that KNO_3 was already decomposed in the body of the fire ball and the reaction of SO_4 was observed with the aqueous solution of the extinguished fire ball and also of the molten matter of the spark received on glass plate.

Next, we determined the velocity of ejected spark particles by taking photograms on rotating Panchromatic plate. The mean velocity was of the order of 50 cm/sec. The shorter spark was slower (mean of four data, 39 cm/sec.) and the longer ones faster (mean of three data, 62 cm/sec.). These sparks are affected by the pressure of air, i.e. under twice the atmospheric pressure the spark becomes about half in length and much more frequent in number compared with the case in the ordinary pressure. From the experiments described above, it seems that the ejection of sparks from the ball is caused by local explosive evolution of gas due to some violent chemical action in which the decomposition of KNO_3 may be involved, and that the ejected particle is exploded by sudden combustion of carbon particles. A similar explosion sparks could not, however, be observed when red hot carbon powder was blown off by an oxygen jet. The molten salt surrounding the carbon powder is therefore supposed to play an

1) These phenomena were already observed by Dr. Yumoto in his experiments

Fig. 6.

Sparks of iron, C=0.7% ; $\times 0.2$.

Fig. 7.

Iron powder shaved with grinding wheel, C=0.7% ; $\times 108$.

important part in determining the characteristic form of sparks of *senkô-hanabi*.

The sparks emitted from an iron tool when it is being sharpened with grinding wheel are very similar in appearance to those of *senkô-hanabi*. Fig. 6 is the case of iron containing 0.7% of carbon. This phenomenon is similar to the present one also in its mechanism, because it is due to the explosive combustion of carbon contained in molten iron as already shown by E. Pitois.¹⁾ Fig. 7 shows the particles of the same iron received on soft Japanese paper. The iron is shaved by the sharp edge of carborandum powder into thin strips, which are melted into spherical drops owing to the heat evolved by oxidation in their journey through air. Among the particles shaved in carbon dioxide we found no such molten drop.

We express our sincere thanks to Prof. Terada for his kind guidance and advices given throughout the experiment.

1) E. Pitois, *L'essai aux étincelles*, Paris, 1924.