PART 1: FAINT METEORS

1. Introduction

The naked eye is able to detect meteors down to approximately $+7^{\mathrm{m}}$ under excellent circumstances in the vicinity of the center of the field of view. Video techniques permit detection of meteors to $+8^{\mathrm{m}}$, and radar meteors as well as telescopic ones may be as faint as $+11^{\mathrm{m}}$.
Photographic methods can hardly compete with these. Nevertheless it is possible to reach $\approx +4^{\mathrm{m}}$ with modern photographic systems, such as Super–Schmidt cameras or very fast lenses combined with fast photographic emulsions.
The photography of faint meteors is necessary for several different goals:

– the derivation of precise radiant positions for meteor showers

– the determination of meteor atmospheric trajectories (heights, distances, velocities)

– the calculation of meteor orbits

– confirmation of meteor activity from suspected radiants

– activity determination in the rare case of meteor storms

But first it is necessary to get a photograph which allows positional measurements, not merely a nice looking picture!

2. Camera

The *camera* body has no great influence overall, since it is effectively only the film holder. Of course, the camera must allow time exposures and the easier it is to handle in the dark the better it is suited for astronomical purposes. In particular, problems may occur with cameras driven by electronics. In this case, it will probably be necessary to switch off most automatic controls (consult the instructions given in the manual first). Long exposures or cold winter nights may cause the operating limits to be exceeded as well.
Long exposures are possible only if the camera shutter has either a “B” or a “T” position. (“B” implies that the shutter is open as long as you push the release button.“T” opens the shutter once you push the release button, and it remains open until you push it again.) If you use “B” on your camera, you will need a lockable cable release, while “T” allows exposures without such a device.

Sometimes a *cable release* may cause troubles. Some cable releases are badly affected by humidity or cold, and should be tested before each use. The exposure might otherwise be ended due to a malfunction at an unknown time, and a meteor missed. An alternative is a fixed release which you can mount in the same manner as a cable release, but without a cable (Fig. 1-2). As the conical camera thread is difficult to produce yourself, you might find suitable components for such a device in your local photo shop or you may be able to obtain it from other advanced amateurs.

Figure 1-1: Typical equipment needed to start meteor photography. It consists of a camera (easy to handle in the dark) with a fast lens (see section 3 for details), a stable tripod, and a cable release.

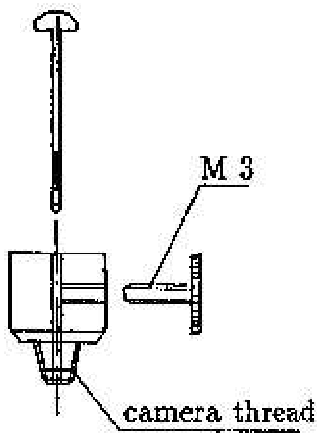

Figure 1-2: Construction of a fixed release as used for many cameras.

3. Lens and film

The number of meteors that can be photographed depends on the properties of the film and of the camera. In this section we will quantify this number based on the following two new concepts:

– The limiting magnitude (LM) of the *lens* for meteors, in other words the magnitude of the faintest photographable meteor.

– The efficiency number (E) of the lens. This number allows the comparison of different optics, and defines an expression for the theoretical photographic hourly rate.

3.1. The limiting magnitude LM

The limiting magnitude is dependent upon the sensitivity of the emulsion being used (g). It is not very useful to try to photograph faint meteors with an ISO 100/21° film (ISO is the international standard way of rating films, described in detail in section 4 on pp. 13-14.), even where a very fast lens is available. On the other hand, as the sensitivity of the emulsion increases, the film's resolution and grain structure get worse. For many films the optimal combination occurs at ISO 800/30°, although very recently produced films give excellent results at ISO 3200/36°.
The focal length (f) of the camera lens also plays an important role in determining the limiting magnitude. As the focal length increases, the field of view becomes narrower and hence the light of the meteor passes faster over the emulsion grains, so the exposure time per grain decreases. We can state that the LM is inversely proportional to f.
Finally, there is one further important factor: the amount of luminosity which enters the camera. The amount of luminosity will depend on the surface area of the lens, hence on the square of the effective diameter of the lens (d^2).
The optical data for a lens is given through its focal ratio, or aperture number $r = f/d$ and its focal length f as in "$f/2, f = 50$mm". This means that $r = f/d = 2$, or, $d = f/r = 25$mm.
Putting all these factors together in one equation we get:

$$\text{sensitivity} \;\propto\; g \cdot f^{-1} \cdot d^2 \tag{1}$$

where:
g the sensitivity of the emulsion (first number of ISO noting)
f the focal length of the lens (e.g. 50 mm)
d the effective diameter of the lens (in mm)
Many published relationships are based on investigations by Hawkins (1964). In practice the following formula can be used to determine the limiting magnitude for meteors in pure white light (only valid under perfect sky conditions):

$$LM = 2.512 \cdot \log_{10}(d^2 \cdot f^{-1} \cdot g) - 9.95 \tag{2}$$

For example let us consider a "normal" lens $f/1.8, f = 50$mm which is widely used. Its effective aperture is $d = f/r = 27.8$mm. Used with an ISO 400/27°-film we calculate
$LM = 2.512 \cdot \log_{10}(27.8^2 \cdot 50^{-1} \cdot 400) - 9.95 = -0.43$
or, for an ISO 800/30°-film we find
$LM = 2.512 \cdot \log_{10}(27.8^2 \cdot 50^{-1} \cdot 800) - 9.95 = +0.33$.
More values for several lenses are summarized in Table 1-1.

3.2. The efficiency number E

At a fixed limiting magnitude (LM) the efficiency number of a camera will only depend on the size of the camera field A, expressed in square degrees. The larger A is, the higher the probability of catching a meteor. First, we determine A by use of the following formula:

$$A = 2\arctan\left(\frac{a}{2f}\right) \cdot 2\arctan\left(\frac{b}{2f}\right) \tag{3}$$

where a and b are the dimensions of the negative (plate) and f is the focal length of the lens, both given in mm.
Let us call X the number of meteors that a camera photographs. When a camera with an $f/d = 2.8, f = 50$mm, abbreviated as $f/2.8$, $f = 50$mm lens photographs exactly 1 meteor then another lens with parameters f, d will catch X meteors:

$$X = A \cdot (d^2 \cdot f^{-1})^{1.21} \cdot f^{0.056} \cdot 10^{-4} \tag{4}$$

It is obvious that this number X will be an important value for the photographer. The number X will allow the photographer to decide which lens offers the highest probability of photographing a meteor. One final formula will yield the photographic sporadic hourly rate N. This relation is again from Hawkins (1964), p. 31:

$$N = A \cdot (d^2 \cdot f^{-1})^{1.35} \cdot f^{0.056} \cdot 4 \cdot 10^{-6} \tag{5}$$

Formulae (2), (3), (4) and (5) were used to compile Table 1-1 below (for $g = 800$). The values given are valid for sporadic activity during "average" nights (in fact, the sporadic activity level varies during the seasons). For the lens characteristics a choice was made which coincides with the equipment used by most *IMO* members. For comparison we also mention the characteristics for a Super–Schmidt camera. Its construction is described in several books about meteor astronomy, for example in Hawkins (1964). All these equations can not give precise figures but allow the comparison of different lenses and the choice of the most appropriate one. Furthermore, you may get a guess for the success rate.

Table 1-1: Camera characteristics; *LM* is given for an ISO 800/30°-film. The value for the 80 mm diameter field (in the first column) refers to the full field of a fish-eye lens (entire sky). Because of the inclusion of near horizon regions an enormous volume of the atmosphere is photographed, but with large extinction and meteor distance from the camera, the values X, N are uncertain for such lenses.

	f mm	$f \cdot d^{-1}$	d mm	LM	A sq.deg.	X	N
24×36 mm^2	28	2.8	10.0	−1.3	3038	2	0.08
	35	1.8	19.4	−0.1	2060	4	0.24
	35	2.8	12.5	−1.0	2060	2	0.07
	50	1.4	35.7	+0.9	1069	7	0.41
	50	1.7	27.8	+0.3	1069	4	0.24
	50	2.8	17.9	−0.6	1069	1	0.06
	75	4.5	16.7	−1.2	491	0.3	0.014
58×58 mm^2	30	3.5	8.6	−1.7	7754	2.8	0.126
	50	4.0	12.5	−1.4	3627	1.8	0.084
	75	3.5	21.4	−0.7	1788	2	0.11
	75	4.5	16.7	−1.2	1788	1	0.06
	80	2.8	28.7	−0.1	1588	3.4	0.19
80 mm ⊘	30	3.5	8.6	−1.7	20625	7.4	0.334
6×9 cm^2	105	4.5	23.3	−0.9	1480	1	0.07
Super–Schmidt	200	0.65	307.	+4.1	2380	553	50.7

Within a certain range of focal lengths (15mm . . . 80mm) we may compare the effectiveness of different lenses using the simplified measure E, defined as:

$$E = d^2/f \tag{6}$$

where d is the linear aperture of the lens, and f is the focal length, both in mm. If you prefer to use the aperture number r, you may write:

$$E = f/r^2 \tag{7}$$

Fast lenses, such as $f/2$, can attain good limiting magnitudes and modern lenses are in most cases of very good optical quality allowing the required astrometric measurements to be made.

Another influence on the rate has not yet been discussed: the direction of the camera. Let us assume an isotropic entry of meteoroids into the Earth's atmosphere. Meteors in the zenith will then appear brightest because of the smallest distance to the camera. For larger distances, i.e. lower elevations in the sky, the intensity decreases with the square of the distance. Next, the extinction increases towards the horizon when the light transmits larger amounts of the atmosphere. On the other hand,

the camera photographs a much larger volume if directed to lower elevations. These influences are discussed more quantitatively in section 5 of Part 6 (Double Station Work).
Visiting a photographic shop, you will find a great variety of very different *films*. First, you should bear in mind that the positional measurements are the main purpose of meteor photography. Another item of importance is the brightness of the meteor. The latter can only be derived from black and white negatives, not from color material (either slides or negatives!). Therefore you should preferentially select black and white films. For details on this see section 4 of Part 8 (Photometric Measurements).

4. Handling black and white photographic material

Most astronomy handbooks mention astrophotography, but the basic concepts concerning photographic processing are not well covered. Most meteor observers are unfamiliar with photography, and will need to know something about the subject before they can apply it to meteors. Beginners may wonder which materials will be needed and how to get the films developed.

4.1. Composition of films and plates

Most amateurs use standard, roll or plate film for meteor photography. These plates or films are composed of a transparent carrier (4) on which a light sensitive emulsion is moulded (2), as shown in Fig. 1-3.

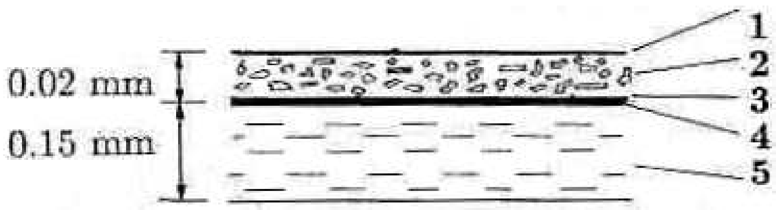

Figure 1-3: Composition of films. The numbers of the layers are explained in the text.

This layer is protected against scratches by a thin layer of hard gelatine (1). Fast films are usually produced with two emulsion layers of different compositions to increase the dynamic range of the exposure span.
Before the emulsion layers are moulded, the carrier is covered with an intermediate gelatine layer (3) to improve the contact with the emulsion layers. This is called the substrate layer. Finally we have the anti-halation layer (5), which prevents reflections back from the film base. The emulsion layer itself consists of gelatine and light sensitive salts. The grain structure and distribution of these salts define the photographic characteristics of the film (fast or slow.)

4.2. Classification according to speed

In the gelatine of the light sensitive layer we find silver halide crystals of varying sizes. Mean silver halide particle sizes range from $\approx 0.05\mu$m for some special high resolution products to about 1.1μm for a common amateur film and about 1.7μm for a medical X-ray film. To "expose" one of these crystals we need a certain number of photons, and thus a certain amount of light. The larger these light sensitive crystals, the higher the chance of collecting the necessary number of photons and the less light energy required to turn them black, thereby creating a latent image "faster". The action of just a few photons on the grains renders each of them able to oxidize certain weak reducing agents in aqueous solution, the grains themselves being reduced to metallic silver, thus forming the negative image (this

is the reason for the relatively high price of black & white films). The chemical effect of these few incident photons is thus amplified by factors of the order of 10^9. The detector quantum efficiency, however, is rather low compared to other optical detectors. It currently lies in the neighborhood of 20% at best.
The grain structure of a "fast" film is rough because of large crystal sizes, and therefore the resolution of fast films is poor. Of course, the precise parameters vary between different manufacturers. Fortunately these highly sensitive materials also have advantages such as long possible exposure time-spans. This means that a large difference in intensity can be transformed into differing degrees of blackening as shown later in Fig. 1-5 and described in section 6, p. 19 ff..
A more fine-grained distribution makes the emulsion less sensitive. For these "slow" films, more light is required to create an image, and the possible exposure time-span is also much smaller.
With the exception of fireballs, meteors are relatively faint objects. Therefore it is of no use to work with slow films in meteor photography. Using the exposure times common for mean daylight exposures we can make the following sensitivity classification, where ISO stands for "International Standards Organization", ASA "American Standards Association" (which both use identical numbers) and DIN "Deutsche Industrie Norm" (which works with a different numbering system). The ASA and the DIN use different definitions for the sensitivity of photographic materials.
The ISO recommendations include the most appropriate methods for current techniques based on experience obtained with these different methods so far. For example, the ISO standard utilizes the standard method of development from America, the record of a specific adopted contrast determination from Russia, and the determination of the sensitivity-point on the characteristic curve (0.1 above fog) from the German standard.

Table 1-2: Classification of films according to their sensitivity.

very low sensitivity material			up to ISO	12/12°
low sensitivity material	ISO	16/13°	to ISO	50/18°
medium sensitivity material	ISO	64/19°	to ISO	160/23°
high sensitivity material	ISO	200/24°	to ISO	500/28°
very high sensitivity material	ISO	650/29°	and higher	

The fine grained, slow emulsions are much more capable of distinguishing details which are close to one another than fast films with their rougher grains. In this regard we speak of a film's resolution and we define this as a measure of the number of lines per millimetre (ln/mm) that can be distinguished separately under ideal circumstances. The typical resolution of some types of black-white negative emulsions are given below (you will find differences from one type to the next, as well as with the kind of development used).

Table 1-3: Resolution of different films, average values.

emulsions for measure-technical goals		2000 ln/mm
slow small-frame camera films	(ISO 25/15°)	350 ln/mm
medium-fast film	(ISO 100/21°)	120 ln/mm
fast film	(ISO 400/27°)	90 ln/mm
very fast film	(ISO 1000/31°)	75 ln/mm

4.3. Selection of film types

Today, highly sensitive films (ISO 3200/36°) with reasonable grain structure (such as the so–called T–grain; T standing for tabular) are available. The trade names for these vary from country to country and also change with time, so it is of little use to sum up all the possible sorts of films presently available. It is up to the photographer to decide which film to buy: always select the fastest film with as fine a grain structure as possible, within your own budget. The general characteristics and advantages have been described above. Manufacturers will usually be able to provide further technical details regarding their own products. Do not store films for long periods because ageing processes – even under favourable storage conditions – reduce sensitivity and contrast, and such degradation will be seen first in situations where you need optimal performance.

4.4. The exposure

The so-called panchromatic materials (used by meteor photographers) are sensitive to all visible light wavelengths, but not in the same degree for all colors. As this is the case, the distinction between different colors in terms of different grey levels does not appear on the film. In order to be sensitive to the light of a given color, the silver chemicals in the film must be capable of absorbing the light of that color.

A typical problem in meteor photography is the way a photographic image is created during the exposure. In 'normal' pictorial photography the photographer exposes the film for a length of time which, from experience, is known to produce a suitable image. A meteor, by contrast 'writes' its image through the camera lens on the emulsion very quickly. Hence, the final exposure time is not only dependent on the light sensitivity of the camera's main lens, but also on the speed with which the projected image of the meteor goes over the grains of the emulsion which is synonymous with the speed at which the meteor moves through the camera field. The faster the motion, the less time the silver grains get to collect the light and thus build up a latent image. In order to expose photographic material there is always a minimum of light required. This may be much light in a short time, or very little light collected over a longer period. At a low light level, however, longer exposure times are required as the film becomes less sensitive to a given light source as the exposure progresses. This is the Schwarzschild-effect.

According to the reciprocity law found by Bunsen and Roscoe (1862), the chemical process in film should lead to the same blackening S if one exposes a film with a high intensity I for a short time t or with a weak intensity for a longer time:

$$S = f(I \cdot t)$$

as long as the product $H = I \cdot t$ remains constant. But this is not the case. The photographic effect of light on an emulsion depends not only on the total number of photons received by each silver halide grain, but also on their rate of arrival. This effect is not normally apparent when exposure times are between 0.001 s and 1 s. Outside this range, for example with high intensity short duration flashes or the low light levels of astronomy, a breakdown of the reciprocal relationship between exposure time and illumination occurs. Any emulsion exposed to a high light intensity for a short time (> 1 s) is blackened more than another exposure with a weaker intensity but for a longer time such that they both have the same product H. This is described as *low intensity reciprocity failure* (see e.g. Malin, 1982). The astronomer Schwarzschild proposed the expression

$$S = f(I \cdot t^p)$$

with the Schwarzschild-exponent $p \leq 1$ (Schwarzschild, 1900). For most of the films, $p \approx 0.7 \ldots 0.95$. It is not a real constant, but depends on the material, the intensity range and the wavelength in question. For X-rays $p = 1$, for very small amounts of light $p \to 0$.

For meteor photography this effect is only partially relevant: the exposure due to a meteor is in the

order of 10^{-4}s for a certain grain, and is thus very short. On the other hand, stars and background light expose a given grain for a much longer time. Therefore, the emulsion becomes less sensitive for these sources exposed to the film for long periods of time while meteors will be affected less. This is most important for the long duration fireball patrol photographs (cf. Part 2, Fireball Patrols).
These very different exposure durations make it difficult to compare the blackening due to stars and background with those of meteors and thus to estimate meteor brightness by direct comparison with star trails. We return to this point in detail in Part 8 of this Handbook (Photometric Measurements).

Table 1-4: Possible exposure times in minutes for different film materials as a function of sky conditions. The sensitivity measure is reduced to the first part of the ISO designation only.

	Exposure times for $f/1.8, f = 50$mm			
	ISO 400	ISO 800	ISO 1600	ISO 3200
very dark sky, no dust/haze	40	30	20	15
dark sky, no scattered light	30	20	15	10
clear sky, city lights distant	20	15	10	5
hazy sky or nearer city lights	10	5	–	–

For the purpose of photographing fainter meteors we choose films of high sensitivity, at least ISO 400/27°, though preferably ISO 1600/33° or even ISO 3200/36°. Such films cannot be used properly in light-polluted areas, hence lower sensitivity films such as ISO 100/21° may have to be used to give reasonable results to keep the background light to an acceptable level. For optimal results you will have to experiment with exposure times and film speeds for a given site under different circumstances, but Table 1-4 can act as a good guide for these values. As a rule, during twilight or with moonlight interfering, meteor photography is not practical and you would do better to save the film for more favourable periods.

5. Additional equipment

5.1. Warming

What additional equipment is necessary? At most sites you will often need a *warming* or other protective device for the lens to avoid dew. The idea behind heating the lens is to raise the temperature of the front lens and, more importantly, the air in front of it by some tenths of a degree. This makes the lens slightly warmer than the surroundings and serves to increase the dewpoint near the lens by a small amount. This requires the dissipation of only a few watts of power and it is advisable to use a low voltage power source to prevent accidents on damp nights.

5.2. Precise timing of the exposures

If you guide the camera you should make control checks of the positional accuracy from time to time. For an unguided camera, the exact time of appearance of any photographed meteor is required. This is a quantity needed when reducing the measurements of the position of the meteor on the image, without which it is impossible to derive the exact position in right ascension. On a 20 minute exposure, the star trails are 5° long, giving some idea of the size of the error involved. This is unacceptably large for precise measurements. Therefore it is absolutely essential to note the beginning and end of the exposure as well as the appearance time of the meteors in or near the field of the camera with a certainty of at least ± 5 seconds. In only 10 seconds the sky rotates by 2.5 arcminutes in right ascension!

In the case of positional measurements it is important to know if clouds were present at the start or end of the exposure since the end points of the star trails are used for reference. Thus, if there are clouds at one or both of these moments, you should note at least 10 stars which were not covered by the clouds, or wait a few minutes to start/end the exposure.

5.3. Rotating shutter

If you make astronomical photographs frequently, you will be familiar with different kinds of non-stellar trails. These might be caused by meteors, but also by satellites, airplanes, fireworks or other moving phenomena (even by somebody crossing the camera field with a cigarette!). Often it is hard to decide which object is which on the image. Some examples are given in Part 10 at the end of this Handbook. Careful observation of the camera field during the exposure should provide the necessary information, but an alternative way to overcome this situation is by the use of a rotating sector or *rotating shutter* usually located in front of the lens (Fig. 1-4). More details will be given in Part 5 (Additional Equipment).
Normally such a shutter is constructed with two wings or blades. The interruption frequency once the blade is rotating should lie between 8 and 50 breaks per second. For positional measurements, particularly in the case of double station meteors (see Part 6 of this Handbook), the interruption frequency chosen will be dictated by the shower under investigation. A higher frequency is useful for shower meteors with a high entry velocity, such as the Perseids and Leonids, while a lower rotation rate is more appropriate for slow meteors, e.g. the α-Capricornids or the κ-Cygnids. A proper choice should produce enough shutter breaks in the trail of a fast meteor, while ensuring the breaks are well separated from each other for a slower meteor. In practice, this is often not achievable. For example, in August we have fast Perseids as well as slow meteors from the α-Capricornids, the Aquarid-complex and the κ-Cygnids all present at the same time. Essentially, the choice is made by deciding which shower is more important to observe at the time. In November, when both the Taurids and Leonids are active, a shutter suitable for Taurids giving a rate of about 15 breaks per second will leave a typical Leonid meteor trail divided into only five breaks.
Consequently, a value of about 15-25 breaks per second is suitable for "average" velocity meteors, while about 25-50 breaks per second are recommended for showers like the Leonids. The very high shutter breaks are only useful in combination with very sharp optics.

Figure 1-4: Rotating shutter used for meteor photography.

A rotating shutter interrupts the exposure periodically which in turn reduces the amount of background light and also decreases the density of the star trails, though these will still appear as continuous lines on the negatives. This will also be the appearance for nearly all satellite trails. By contrast, meteors move considerably during just one revolution of the shutter, hence meteor trails will appear as dashed lines on the photograph. The length of each segment of "light" along the broken trail is proportional to the instantaneous angular velocity of the meteor at that point. The shape of the rotating shutter can be varied depending on the observational circumstances at your site. If you have a bright sky background, you may wish to use shutter wings with an angle of about 120°. In this case $\frac{1}{3}$ of the meteor trail is exposed on the frame, while $\frac{2}{3}$ of the trail is "blanked" due to blockage by the shutter. This reduces the data available for meteor trail photometry (ie. to derive a light curve), but will not affect the accuracy of information needed to derive a radiant association. Conversely, under favourable circumstances it is desirable to use a rotating shutter with 60° wings (or even less). The disadvantage of this setup becomes apparent when bright meteors (fireballs) are photographed as the exposed parts become too bright and the light may "spill-over" to the breaks.

Unfortunately, the use of a rotating shutter will not eliminate all identification errors. You may find some trails of airplanes look like interrupted meteor trails, or that a rotating (blinking) satellite may cause a similar trail. Thus, even when using a rotating shutter one should visually watch the area covered by the camera while it is operating. Some examples of different non-meteor trails are shown in the appendix containing photographs (Part 10).

Practical experience has shown that the use of synchronous motors for rotating shutters is a must. The frequency of such motors is only dependent on the power frequency (60 Hz in North America and 50 Hz in Europe). Even when these motors are used it is very important to occasionally check the speed of the shutter as they can be retarded by residues of oil and dust covering the axle of the motor. A good test for this utilizes a stroboscopic device. In this test, the shutter is lit by a lamp whose frequency can be changed continuously. By finding the flicker frequency of the lamp such that the shutter is seen to be fixed, you can find the shutter's rotation frequency . Depending on the number of shutter blades, you will find several lamp frequencies which a fixed appearance – in this case the lowest frequency which leaves the shutter fixed is the true frequency.

Finally it should be noted that a rotating shutter also helps prevent dew formation on the lens by circulating the air in front of the lens. However, do not rely on this and use proper lens heating.

5.4. Getting started

Appropriate equipment should include:

(1) A camera which allows long exposures, is easy to handle in the dark and which is not influenced by dew and cold

(2) A fast lens (for example $f/1.8, f = 50$mm)

(3) A warming device for the lens

(4) A rotating shutter with a synchronous motor giving about 15 breaks per second;
for meteors of high velocity showers, such as the Leonids, 25 breaks per second

During the observation you should note the following information for each exposure:

(1) Precise time for the beginning and end of the exposure (use UT only to avoid confusion)

(2) If possible, exact time of appearance for all bright meteors (about 1^{m} or brighter)

(3) Notes about other moving objects crossing the camera field

(4) Some notes about the sky conditions, specifically about clouds near the start or end of the exposure (remember to note at least 10 stars which are not covered by clouds at these moments to allow position measurements to be made later)

These notes should be written up in a book kept only for this purpose, or single sheets put together in one file in order to allow easy identification and provide information years later.

6. Development of the exposed material

Nothing can be seen on film after an exposure but undeveloped film or plate. Only during the development process does the image become visible. There are many different developer chemicals available. The variety in choice is a reflection of the many different purposes of photography. The developer will influence the sensitivity, the overall contrast, resolution, and fog formation on the final photograph. For meteor photography, sensitivity is the single most important aspect, while resolution is also of importance when it comes to the measurement of the negatives.

In spite of the fact that commercially available developers are of good quality with regards to their composition as well as their reliability, it often happens that two users of the same developer, working in the same way, obtain different results. The reason for this is that many factors influence the developing process.

The development of almost all negative films is a function of the time the film spends in the developer, the developer's temperature, its concentration, as well as the agitation applied to the developing tank. To get good results, one has to assume the information provided by the manufacturer is accurate and gain some trial and error experience. For continuous development, closed developing machines with constant feeds can be used, but it is also possible to use small tanks with an internal spiral to hold the film in the so-called "tumble" method. In order to get the process running smoothly with regards to time and temperature, a few things are important:

– accurate time reading

– calibrated thermometer and measuring glasses

– agitation of the plate or the film during the developing process around in the developer (always according to the instructions of the manufacturer).

– caution with the use of tap-water: its composition is not the same everywhere and may contain some impurities. It is recommended that such water be boiled before use to remove some minerals or better yet use distilled water.

It should also be noted that some combinations of film type and developer are more sensitive to changes in these circumstances than other combinations. Try some combinations and find your favourite one. Films that have passed their expiry date often give a slack image, while insufficient darkness during the development will create fog. Preference of a liquid or powder developer is a personal choice. For a beginner, the liquid may be better as it is easier to use, but the main criteria should be the best possible improvement of the film's sensitivity by the developer, the creation of a smooth gradation in darkness levels, and a minimum increase in the grain size. Thus, ask for a fine-grain developer with good sensitivity.

It is not possible to get out any more detail at this stage of developing than that obtained by the latent image over the exposure time.

It is of little use to sum up all the developing products available from manufacturers. In many journals you will find tables comparing different developers and their resulting characteristics for certain films. Your local photographic shop may be able to give you good advice in this matter. It should be emphasized, however, that meteor photographs should ideally not be given to commercial photo shops. If you take this risk it may mean that all you receive in return is another (new) film as they may throw the original away when they are unable to decipher any obvious pictures on your film. In good developing shops it is possible to specify "development only" or "print all". Nevertheless, it remains risky to give films to commercial developing shops. Therefore the only safe method is to develop the films yourself or have another amateur who is acquainted with the aims of meteor photography do this.

When developing your own film the primary points to consider are:

(1) We want to obtain precise positions.
⇒ As some of the high sensitivity films already show a relatively large grain size, we should use a developer which does not further increase this.

(2) We wish to analyze rather faint meteors.
⇒ The developer we chose should work to further increase the film's sensitivity, hence the smallest activated regions, exposed with the smallest amount of light $I \cdot t$ must be developed into detectable blackening (in Fig. 1-5 the lower ends of the characteristic curves).

(3) We have many objects (stars, meteors) of very different brightness on our film.
⇒ Therefore we should try to transform all these differing light intensities into different grades of blackness on the negative (Fig. 1-5).

These three facts suggest fine grain equalizing developers as the best overall choice for developers.

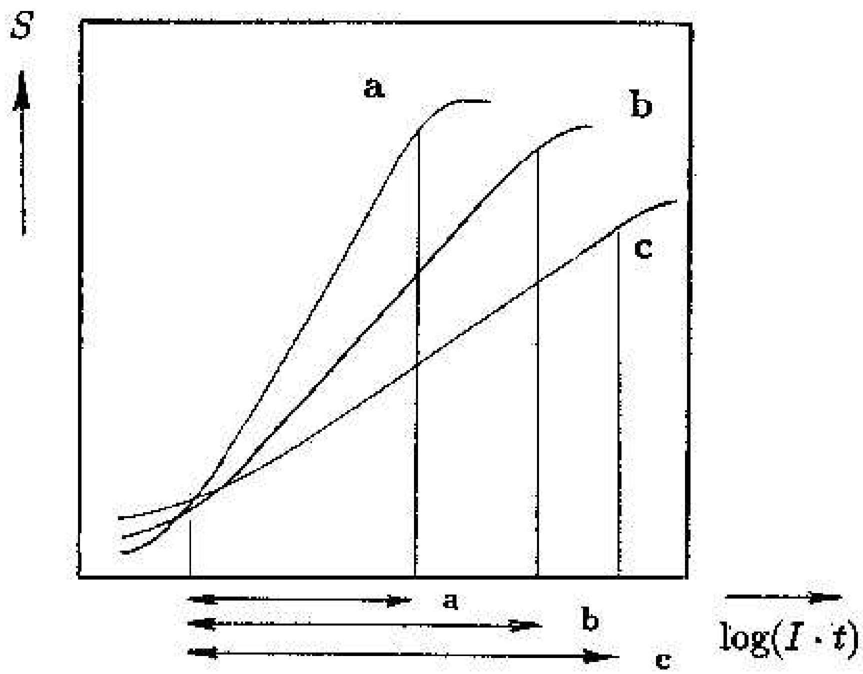

Figure 1-5: Characteristic curves of different slope (steepness) achieved by different types of development: **(a)** with a rapid developer, **(b)** using a "standard developer", and **(c)** with an equalizing fine-grain developer. Note the different ranges of $I \cdot t$ which can be transformed into different amounts of blackening S. Although the curve (a) seems to look best at first, (c) is more suitable for analysis, particularly for photometric measurements as it has a larger dynamic response in $I \cdot t$ for a given change in dark level (i.e. a shallower slope).

While the developer is of considerable importance, the fixing bath is not. You should, however, ensure that sufficient fixation and final watering occurs (at least 20 minutes) to avoid damage when you store the films. More information on the techniques of film development can be found in any of the recommended photographic texts in the reference list at the end of this book.

7. Your archive

After a relatively short time you will have amassed a large collection of photographs and negatives. In order to find a specific negative it is necessary to establish a storage and retrieval system. First, you must decide whether you will store all the photographs or only those showing meteor trails. In the latter case we strongly urge you to store the preceding and the following exposures in order to uncover any instrumental effects which may only become apparent at a later time. Before you throw an image away, you should check it carefully. Consider also the fact that each image of the sky may become of interest to somebody searching for a phenomenon perhaps years later. The probability that any one photograph contains important information is not very high, but it is nevertheless finite.
The notes written during or after the observation should be either directly assembled with the negatives (e.g. in protective envelopes), or connected to the negatives based on an identification system which allows the association of any negative with its data unambiguously. For example you might note numbers and/or letters along the edge of negative strips or at the edge of large films using a permanent ink pen. One example for different sized films is given in Fig. 1-6. Although prints of negatives can be made many times and then associated with their original data, it is advisable to note this data on the reverse side of the prints. If you need a particular photograph, say for a publication or identification with another observation, you may then find it easily.

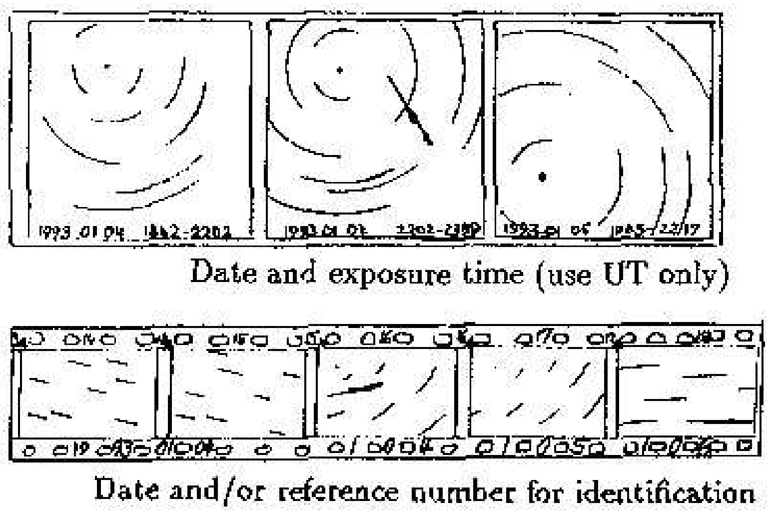

Figure 1-6: In your archive the negatives should be marked according to a specific system for identification. These examples, for 35 mm-film and films of 120 (60 mm) format demonstrate one possible scheme.

For storage we recommend keeping film in strips of 5 or 6 exposures each. Avoid storing the film in rolled form as this can easily cause scratches on the emulsion. Paper or plastic bags suitable for negatives should be employed. Furthermore you can always note additional information on the outside of the bags. This is of assistance when searching for particular exposures. A stout wooden or metal container should house your records when you have prepared them for storage to avoid damage by dust, accidental spills etc.

8. Photographic observations during a meteor storm

At this point in the Photographic Handbook we describe a possible solution for scientifically useful photographic observations during extraordinary events – meteor storms.
If the number of visible meteors becomes too large to be counted, we generally speak of a meteor storm. This, however, is not a well-defined term. It is nevertheless a problem of great interest to determine the actual activity level during these events. Visual observers cannot accurately count hundreds or thousands of meteors per hour. Radio techniques may have problems in recording this phenomenon due to saturation effects caused by the superposition of signals from many meteor trails simultaneously. For the investigation of the meteor stream responsible for such storm events it is very important to obtain reliable magnitude data as well as precise numbers of meteors per time unit (Koschack, 1993). During periods of normal shower maxima the number of photographed meteors is far too small for an activity analysis. But perhaps you are familiar with the famous 3-minute-exposures taken during the 1966 Leonids containing some 40 meteors? Generally, during such a meteor storm we try to record as many of the fainter meteors as possible. Therefore, we may follow the guidelines established in this chapter for capturing faint meteors during periods of normal activity. The aim of determining numbers of shower meteors and their apparent magnitudes, however, introduces some additional constraints. A major goal in studying meteor storms is to calculate spatial number densities (flux densities) in the meteor stream. Thus we need a reliable record of meteors per magnitude range per time unit. Because of the factors involved in the ability of a lens-film combination to photograph meteors of different angular velocity and brightness, there are several, mainly geometrical reasons for the following restrictions:

- shower meteors move faster the closer one gets to 90° distance from the radiant
- shower meteors move faster near the zenith than near the horizon
- the film will record fainter meteors of low angular velocity, or only bright meteors of high angular velocity

Of course, there is no possible camera field which is not affected by these factors. But we may minimize their influence.
The camera should be pointed 180° away from the radiant in azimuth. If a wide angle lens is used, the lower limit of the field should be 10…20° above horizon. For a standard lens of $f = 50$ mm the elevation of the optimum field center depends on the elevation of the radiant h_{Rad}. The most suitable elevation of the field center h_{fc} is recommended in Table 1-5:

Table 1-5: Elevations of the field center h_{fc} for meteor storm photography using a standard lens depending on the radiant elevation h_{Rad}. The azimuth of the camera should be opposite to the radiant.

h_{Rad}	h_{fc}
0°	90°
20°	80°
40°	70°
60°	60°
90°	45°

It cannot be predicted in advance which exposure time will be most suitable. If the activity exceeds the ability of visual counting, perhaps a 10 minute exposure is appropriate. In the case of a further increase in activity, 2 minutes may be long enough.

For each of the photographs the following data are required in order to permit a scientific analyses to be made:

– date

– the exact beginning and end of the exposure (± 1 s; in UT)

– the approximate field center in α, δ

– site location and its geographic coordinates

– focal length and speed of the lens

– film type (sensitivity, format)

– observer

For the analysis of such events it is expected that the *IMO* will establish a research group devoted to each outburst. Therefore, look for instructions given through the *IMO* journal *WGN* or other information regarding the data handling, who to send the information to and which data are required.

9. Use of a video camera

If you have access to a video camera you are encouraged to use it for meteor work as well. Although normal color camcorders are limited to about $+2^{\mathrm{m}}$, which is roughly comparable with the meteor limiting magnitude achieved with a standard lens (cf. Table 1-1 on page 12), the precise timing and frame by frame analyses possible with video equipment compensates for sensitivity limitations. Better sensitivities can be obtained with special high sensitivity monochrome video cameras, or with image intensified video cameras (Hawkes, 1990a).
Use the largest aperture possible with your video camera lens. If it is a zoom lens, you will want to select a fairly wide angle. Once you have selected a *zoom* setting, do not change it during the course of the observations. Set the focus to *manual* at infinity, as some types of automatic focus mechanisms will not operate properly when aimed at an almost black sky. For most purposes you will not want to use the electronic shutter available on CCD video cameras since the sensitivity will be further impaired. Some observers may, however, want to use this feature to specifically look for wake (see Part 4 of this Handbook: Meteor Trains). In this case be sure to note the electronic shutter speed used (e.g. 1/1000 s).
Turn the time display to *on* and set it to the finest time increment possible. Synchronize your clock time to a standard time signal. If no video time signal is possible with your camera, briefly blank the picture (by covering the lens) at several recorded times. Recording a short wave radio time signal on the audio track of the video recording offers another timing option (or more simply, using a microphone to place time markers on the audio track according to the time indicated on an accurate and calibrated clock).
Use high quality video tape, and in most cases it is preferable to use the highest recording tape speed possible (e.g. SP in VHS, Beta I or Beta II).
Unless a clock driven equatorial mount is available, use a firm tripod with a fixed direction. Select an observing direction in the same way suggested for photographic work, but adjust it as necessary to make sure that a minimum of three stars are visible in your field of view.
It will assist with photometric corrections if, at the beginning or ending of your observing period, you record several minutes with the same camera settings but with the camera skewed at angular rates roughly corresponding to that of the expected shower. Note the identifications of the stars used in the test.

Immediately after the observations make a copy of the video tape. It is acceptable (perhaps even preferable) to make this copy on a slow tape speed (e.g. SLP in VHS or Beta II), since frame by frame advance is better on most machines with slow tape speeds. In making the copy of your tape use the *video in* and *video out* connectors, rather than the RF modulated signal. Be sure to use shielded cables intended for video work in making the copy.
Carefully review the tape at least once (preferably twice) to make a listing of all meteor occurrences. This will make it easy for others to complete the analysis of your observations. For each meteor note the following:

1. time (UT) to the nearest second
2. position of meteor on the screen
3. apparent direction of motion
4. apparent angular speed (approximate)
5. approximate apparent luminosity, in magnitudes

Send this information to the VMDB responsible as soon as possible.

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