PART 5: ADDITIONAL EQUIPMENT AND CONSTRUCTION HINTS

1. Rotating shutters

1.1. Reasons for the use of a shutter

It is possible to derive the mean velocity and deceleration of a meteor, required for the computation of a heliocentric meteor orbit, if we know how long the luminous appearance lasted. As the duration of a meteor trail is less than one second in most cases, it is rather impractical to use a stop watch to estimate this time and we have a more accurate device, which can be easily constructed, called a rotating shutter in any case. The shutter is a disc with two or more open sectors which is placed before the camera lens and once in rotation will interrupt the exposure at regular intervals. The rotation speed and shutter blades are designed to give several interruptions during the time of a meteor's appearance which will produce a dashed line on the negative as the meteor's trail. Star trails will remain as unbroken arcs, however, unaffected by this process.

1.2. Other concepts

In principle, also other possibilities to interrupt the exposure at regular time intervals are applicable. At the IMC '88 Steyaert (1988) reported about the use of an LCD (Liquid Crystal Display) instead of a rotating disc. A LCD of 5×5 cm^2 was mounted in front of the camera lens. The reaction of such a LCD slows down with the temperature. Therefore it was heated to about 15°C. The advantages are the light construction, low power consumption, high accuracy when used with an oscillator, safety of use, lack of mechanical vibrations, and the possibility to easily changing the frequency and the ratio between dark and transparent phase (the latter is equivalent to the change of the angle of the shutter blades described below). Principially, such a shutter could also be integrated into the camera. There are no applications of LCD shutters known for regular use so far. Perhaps the disadvantages are not neglectable: the transmittance is of the order of 45% only, i.e. there occurs a loss of about 0.9^{m}in meteor brightness. The breaks are reported to be not sharp, especially when approaching the upper limits of the frequency (25 s^{-1}).

1.3. Construction of a rotating shutter

MOTOR

A bicycle dynamo suits this purpose when linked to the electricity mains by a 6 Volt alternating current transformer. The dynamo, which has to be started by hand, behaves as a synchronous motor with a number of rotations per second equal to the frequency of the electricity mains (50 Hz) divided by the number of pole pairs of the dynamo. Most common types of bicycle dynamos have 4 pole pairs, which makes the number of rotations per second equal to $50/4 = 12.5$. If the shutter has two blades (sectors), this corresponds to $2 \times 12.5 = 25$ interruptions per second.

To find out how many pole pairs your bicycle dynamo has, you can pass 6 Volts through it and take it in one hand. With the other hand you turn the little tyre wheel through 360°. You will feel some resistance (shocks) at certain points, twice as many as there are polar pairs. A dynamo with 4 polar pairs will show 8 points of resistance in one revolution, for instance. It should be pointed out that there are sometimes problems with this kind of motor in regular use.

However, experience shows that such bicycle dynamo motors often lead to problems if used for regular work as in the case of fireball patrols.

Alternatively, you may use a synchronous motor working with a 220 Volt alternating current. Preferably such motors should give 375 rotations per minute (equal to 6.25 rotations per second). Equipped with a two sector-shutter you will then obtain 12.5 breaks per second on your film. When using a relatively high voltage like this with your camera set-up an earth connection for the whole camera is recommended (in darkness and under damp conditions this is for your own safety). Normally, such synchronous motors have to be started by hand, and problems may occur if the power supply is interrupted which may especially happen on expeditions.

THE SHUTTER DISC

The diameter of the shutter disc must be as large as possible in order to give the blades sufficient tangential speed of the blades relative to lens. When the blades cover the lens very quickly breaks of the meteor trail will become much sharper.

Care must be taken if a rotating shutter is working and operations of the camera are necessary in the dark, like starting a new exposure. Some training is recommended to avoid injuries due to the rotaing shutter blade.

A suitable diameter for a dynamo driven shutter is about 30 cm. Larger shutter may need to be started with an electric drill, to get the shutter to the right rotation frequency by use of a friction connection. Starting a shutter is often not without some problems. It is possible to have to start over and over again as the motor must be brought to the exact rotation frequency before it will operate.

The most useful material from which to produce the disc for a rotating shutter from is beyond doubt an aluminum plate of less than 1 mm thickness. On this aluminum plate you should draw a circle with a diameter of 30 cm divided into 4 equal sectors. With a hacksaw the disc and the two open sectors can be cut out. In this case the shutter will have two blades of 90° but it is possible to choose other angles for these blades. Most photographers use rotating shutters with 60° blades. It is very important to work very precisely and carefully when sawing out the open sectors. When the weight is unequally distributed over the shutter, its accuracy will decrease due to vibrations. Next, the sharp edges should be filed down and one side of the shutter should be painted matt black (use black board paint). This black side has to be aimed towards the camera lens.

Right at the central point of the shutter you should drill a small hole where the shaft of the dynamo will be placed. It is essential that this point corresponds to the point of equilibrium of the shutter in order to avoid vibrations once in use.

The advantage of using a shutter like this is that the exposure time can be extended before the same degree of fogging due to moonlight or light pollution is attained. For a 60°-blade rotating shutter for instance, the exposure time can be extended by more than 30%; for a 90° blade rotating shutter by over 50% (this is possible because of the low intensity reciprocity failure, described in detail in Part 1).

Many amateurs have different types of shutter discs; for instance a 60° and a 90° blade shutter. The

most common disc (60°) is used for nights without light interference, the other one for less favourable nights (with streetlights or the moon).
Probably a 90° shutter is most suitable for fireball patrols when exposures will exceed several hours. 60° blades will leave shorter breaks and are therefore preferably applied for fast moving meteors, like the Leonids. In the case of bright meteors at a low angular velocity, breaks may become overexposed and thus badly visible.

HOW TO PLACE THE SHUTTER DISC ON THE MOTOR AXLE
Attaching the disc on to the dynamo may cause some trouble. Many photographers successfully use one of the methods shown in Fig. 5-1. For example, the shutter disc is placed between two screws if the axle of the motor allows to put a thread on its top (about 6 mm are needed), as shown in Fig. 5-1 (right). The disc-hole must not be too large.

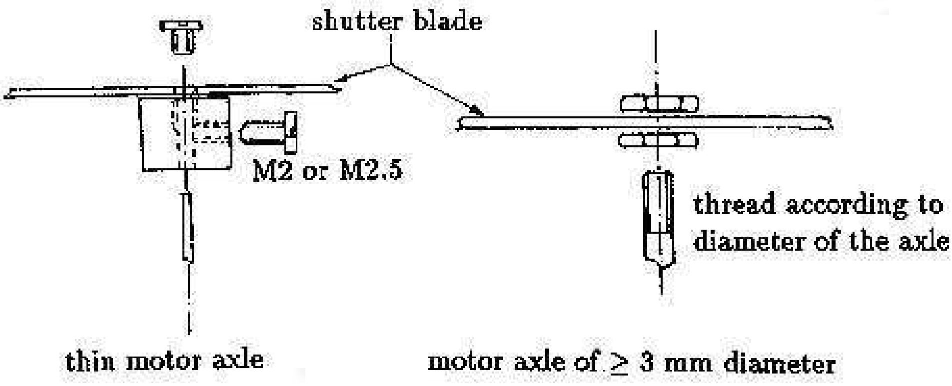

Figure 5-1: Mounting of the shutter disc on the motor axle depending on the axle diameter. The thread to fix the shutter blade must be arranged according to the actual sizes; the measures given here should be regarded as examples.

If you use a synchronous motor with a thin axle, you must find out a method to mount the shutter disc yourself properly. It must be well connected with the motor axle and well centered. Although it is possible to glue the shutter disc to the motor axle, a removable connection is preferable. Perhaps a screw may fix the blade well (Fig. 5-1, left).
Remember that synchronous motors often do not start automatically when you switch them on. Thus it is recommended to prepare a possibility to start them by hand, for example the motor axle can be prolonged to be easily reached. This must be considered especially if the motor and shutter are placed within a self constructed camera box (Fig. 5-2).

MOUNTING THE ROTATING SHUTTER
The camera and the rotating shutter must be mounted separately to avoid vibrations. The use of two different tripods is strongly recommended; one for the camera and one for the rotating shutter. The latter can be home-built.
The major enemy of a rotating shutter is the wind. Wind has a decelerating effect on the blade. Consequently the actual number of rotations can be far below the theoretically assumed frequency. Therefore, try to protect the disc of the rotating shutter, for instance by placing it into a half open box.
The camera has to be mounted in such a way behind the shutter blades that the entire lens is covered at every rotation. Please pay especial attention to this when using wide angle lenses.
As already shown in Part 2 (Fireballs) it is possible to include the shutter inside the “camera” itself (Fig. 5-2). This avoids problems due to the wind and because you may use a very thin and quite

small shutter disc the vibrations are minimized too, providing the disc is not centered badly. Indeed, this set-up requires a very precise shutter balance, since optics, film, and rotating shutter are not separated, and all vibrations will badly affect the quality of the image.

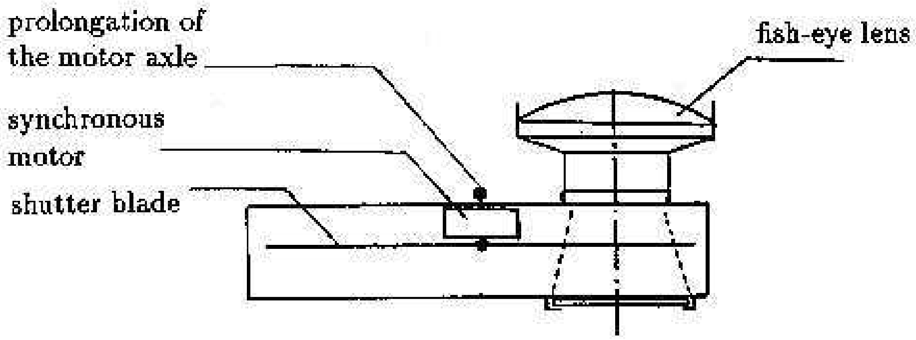

Figure 5-2: Construction where the rotating shutter is within the camera box. Note the prolongation of the motor axle outside the box for starting the shutter. Although the blade may be quite small and does not weigh a lot, it must be well centered to avoid vibrations.

COMPUTATION OF THE TIME DURATION OF A METEOR

Once a meteor photograph with a shutter-interrupted meteor trail is obtained, it is easy to determine the duration of the meteor's appearance. Let N be the number of streaks, T the number of revolutions per second of the shutter and B the number of blades, then the duration d (in seconds) is given by:

$$d = \frac{N}{(T \cdot B)}$$

Example: on the meteor trail we counted $N = 30$ streaks, the shutter ($2 \times 60°$) we used made 25 revolutions per second:

$$d = \frac{30}{(25\ \mathrm{s}^{-1} \cdot 2)} = 0.6\,\mathrm{s}$$

Visual observers may have estimated a longer duration as only the brightest part of the trail may have been photographed.

STABILIZATION OF THE ROTATING SHUTTER

In order to reduce the uncertainty of the duration of a meteor, we may develop a device to stabilize the rotation frequency of the shutter. A rotation stabilizer (for a shutter motor on battery current) is based on light detection. A light sensitive transistor catches the light of an IR LED placed above it on the opposite side of the blades. The light beam is interrupted periodically by the shutter blades, which creates pulses. The duration T of these pulses is inversely proportional to the rotation frequency. These light pulses are compared to an electronically generated pulse of constant frequency. When the generated pulse turns out to be shorter (longer) than the measured pulse, the motor is running too slow (resp.too fast). A solution is to have more (less) electric current in the motor, to compensate for the discrepancy in the rotation frequency. Care should be taken with small rotating shutters as sudden increases in electric current can cause some damage. This problem will not occur with rotating shutters with a sufficiently large moment of inertia (sufficiently heavy shutter disc).
Whether you use a frequency stabilisation or not, it is recommended to check the rotation's speed by using a stroboscopic lamp. There are such lamps available which will allow a shift in the frequency

which permits the determination of the precise frequency of rotating objects. Such rotating objects seem to stand still if the frequencies of the light emitted and the rotation are identical. **Use such a lamp only for checking to avoid danger for your fingers which easily may be put between the rotating shutter blades.**

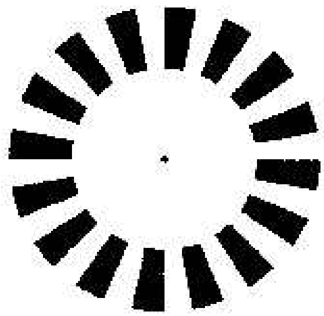

Figure 5-3: This pattern can be copied and placed at the shutter disc. If lit with a stroboscopic lamp, the rotation frequency can be checked.

HOW TO BUILD A STABILIZER FOR A ROTATING SHUTTER

The accuracy of the rotation frequency of the shutter is very important when deriving the velocity of the meteoroid afterwards. The velocity is in turn essential for heliocentric orbit calculations. In order to obtain these final results we need to know the rotation frequency as accurately as possible. Moreover we need to be certain that this rotation frequency remains stable during the entire period of the observation. Some ingenious devices have been developed by amateurs in the past to ensure this and people who are interested in such devices should contact the *IMO* Photographic Commission. See also the device description below.

In most cases observers will make use of a feed connected to the electricity net. Normally the voltage is constant, although this may vary strongly, especially in areas with sparse population. A lot depends on the distance of the user from the closest high voltage distribution centre. Measurements during multiple station photographic campaigns in Europe have indicated that voltages may vary by ±30V. A steady voltage is essential for the tension delivered to the shutter by the motor. Too high a voltage is very bad for the motor (wear and tear) and may even set the motor alight. In some regions the voltage varies constantly and in such a case it is simply impossible to keep to the correct rotation frequency of the shutter.

The best solution is a portable generator with a continuous display of the number of interruptions per unit time. A digital display allows the photographer to keep an eye on the reliability of the rotating shutter. Ignoring these aspects of meteor photography may result in a major disappointment if it turns out that the assumed constant rotation frequency of the shutter was not constant at all. Computing orbital elements from such poor photographic data is virtually useless.

2. Lens heating

Many observing sites are damp at night and this can be a disaster for optical equipment. While optics manufacturers produce dew protection devices for telescopes, most photographers do not have equipment to keep dew off lenses.

Most meteor photographers therefore build their own lens heaters, which are mostly very efficient. The commonest lens heaters dissipate about 20 Watts close to the lens of the camera and in this way the temperature near the lens is kept slightly higher than the surrounding air temperature. This is

just enough to keep dew off the lens, without creating any warm-air turbulence.
There are many possible ways to construct lens heaters.

Some examples include:

(1) Take a film bobbin from a 120 roll film and wind up about 5 meters of wire of resistance 2.5 Ohms per meter on it. Protect the bobbin and the wire with sticky tape and use a 6 Volt power source. This heating element feels warm in the hand.

(2) An alternative is to link a number of small resistors in series until the required temperature is reached. The chain of resistors can be placed in a plastic tube if necessary. A 6 Volt power source will do here as well.

(3) Another good way to keep the dew off is to attach a tube of brown paper to the lens house with an elastic band. The tube projects a few centimeters in front of the lens, and is supposed to work well.

The heating elements have to be held by 2 or 4 pieces of elastic in front of or under the camera lens. This rather primitive fastening has the advantage that it can very quickly be made ready for use.

3. The spectrograph

3.1. Introductory concepts

As you may know, visible light covers only a very small part of the electromagnetic radiation spectrum. White light is composed of radiation with different frequencies or wavelengths λ expressed in nanometers (nm) between about 400–700 nm (see Fig. 5-4).
In spectroscopy you often will find the unit Å(for Ångstrøm) instead of nm, with 1 nm = 10^{-9} m, 1 Å= 10^{-10} m, thus 10 Å= 1nm.

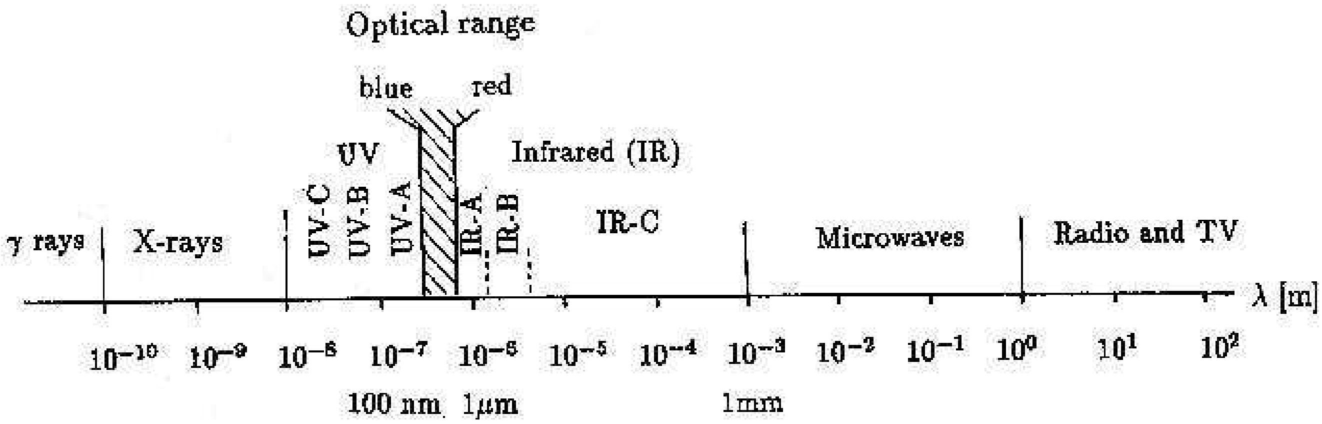

Figure 5-4: Electromagnetic spectrum.

A given atom or ion can remain stable at a well-defined energy level. When an atom is modified from a higher to a lower energy level, an amount of energy will be given out as radiation of a specific wavelength (emission). This wavelength typifies each kind of atom or ion if the energy level transition occurs. As a given wavelength is absorbed, so the atom or ion changes to a higher energy level.
Likewise the luminosity of a meteor is composed of different wavelengths from which we can learn more about the composition of the meteoroid as well as the composition and state of the Earth's upper atmosphere. In order to study this we need to separate the meteor's light into its various wavelengths. This is possible when we put a prism or a diffraction grating before the lens of the camera. Some advantages and disadvantages of the use of a prism or a grating are discussed in Part 3 (Meteor

Spectra), on p. 37 ff. Either dispersing element can be applied successfully, but a prism is the cheaper alternative. The probability of photographing a good spectrum however, is much smaller than with a more expensive diffraction grating.

3.2. The prism

When using a prism with a refracting angle $\alpha = 45°$, the limiting magnitude for photographic meteors will be reduced by $3^{\mathrm{m}}$to 4^{m}compared to the direct imaging. This decrease in magnitude can be reduced somewhat when a prism with a refracting angle $\alpha = 25° \ldots 30°$, perhaps made from a glass with a higher refractive index n is used. The amount of absorption will be less because of the shorter path length through the glass. Hence the decrease in meteor limiting magnitude will be of the order of $2^{\mathrm{m}}$to 3^{m}. This means mainly fireball spectra can be photographed.
Regarding the limiting magnitude and the spectral resolution we have to find a compromise: a wide angle lens $f \leq 30$ mm will concentrate the light into a rather narrow trail. The spectral resolution however is poor, and details of the spectrum will be lost. Features of a spectrum can be improved by using a lens with a long focal length, say $f \geq 80$ mm. In this case the field of view becomes rather small and the chance of photographing a spectrum decreases again. A focal length $f \approx 100$ mm combined with a 6×6-format camera, or an even larger film format, can compensate for this. For such tasks old-fashioned cameras may be very useful.

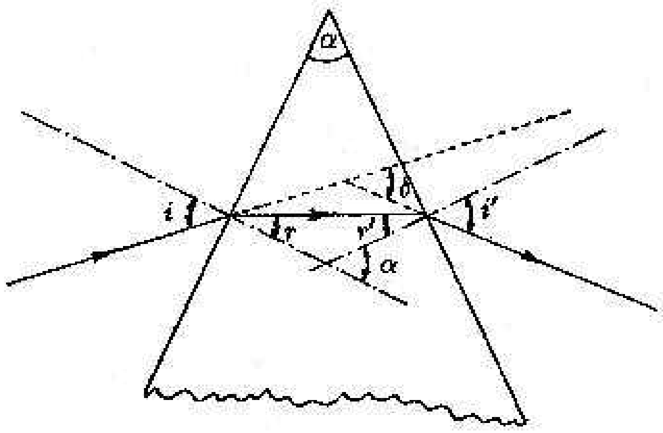

Figure 5-5: Light refraction in a prism.

Fig. 5-5 shows the refraction of light in a prism. The following equations are valid (cf. also Fig. 5-5):

$$\sin i = n \cdot \sin r$$

$$r + r' = a_a$$

$$i + i' - a_a = \delta$$

Where n is the refractive index and a_a is a characteristic number for the sort of material the prism is made from. The value δ is called the deviation relative to the angle of incidence. Since the index of refraction n depends on the frequency or wavelength, then the deviation angle δ will also depend on this wavelength. When the incident light beam (for instance of a meteor) is composed of different frequencies, every component will assume a separate deviation angle δ. This effect is called dispersion D:

$$D = \frac{\mathrm{d}\delta}{\mathrm{d}\lambda}$$

Our meteor spectrograph needs an n-value as large as possible. The best materials are in order of suitability: silicate flint-glass, boric flint-glass, quartz, and silicate crown-glass.

3.3. The diffraction grating

The use of a diffraction grating is based on the principle of interference, where wavelengths are intensified or weakened. Such gratings are made of optical glass with a thin transparent film smoked onto one side. The less expensive gratings have parallel lines etched in this film by using a diamond or a laser beam. The number of etched lines varies from 20 to more than 1000 per millimeter. Due to the often poor geometric quality of such cheap gratings we cannot expect first class images. Moreover, the transparency is very poor, which is most unfavorable for the limiting magnitude (and thus also for the possibility of catching a spectrum).

Better, but much more expensive, gratings are made with fine laid-up threads (for instance Rowland gratings). The much better geometric quality and the high degree of transparency improve the probabilities of capturing a spectrum considerably.

When light of different wavelengths falls on a grating, the various components form diffraction maxima at different angles ϑ (Fig. 5-6).

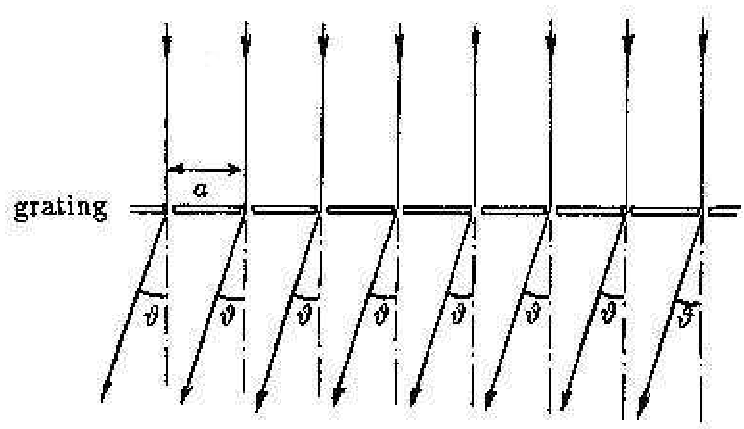

Figure 5-6: Light is diffracted in a grating with a distance a between its slits (lines) by the angle ϑ, which depends on the wavelength λ. The light passing through each slit then interferes with the light passing through the other slits. The result is a series of spectra as shown in Fig. 5-7.

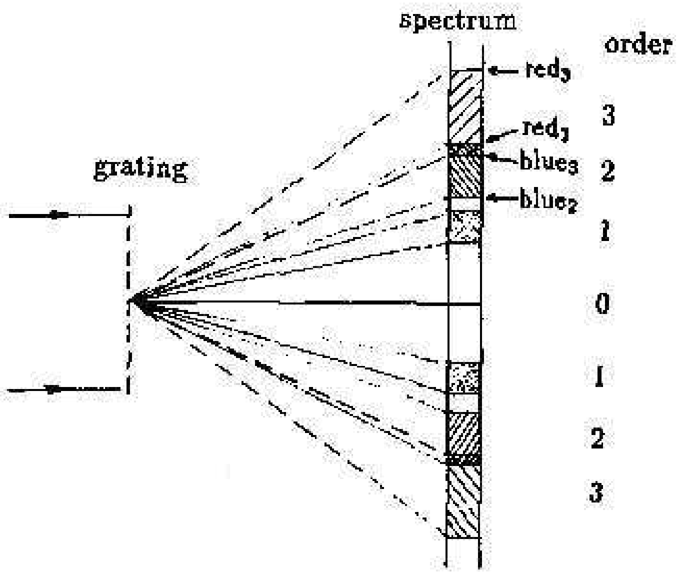

Figure 5-7: Light passing through a grating gives
(i) a bright zero-order image, where all wavelengths coincide ("white"), and
(ii) spectra of higher order n with decreasing intensity.
Since the dispersion D increases with the order number n, the orders overlap. (Note that for simplicity the lens behind the grating necessary for the image is not shown in the figure.)

A series of maxima for all wavelengths of a given order makes up a spectrum. In this way we have spectra of the first order, the second order, the third order, etc. The longer the wavelength, the larger is the deviation for a given order. Thus the deviation is larger for red light than for blue. With a prism this works the other way round.
The dispersion D of a grating is given by :

$$D = \frac{\mathrm{d}\vartheta}{\mathrm{d}\lambda} = \frac{n}{a\cos\vartheta}$$

(Where $n = 0, \pm1, \pm2, \ldots; a$ is the distance between lines on the grating)
This shows that the higher the order, the larger the dispersion becomes. For order 0 ($D = 0$) all wavelengths fall together (see the example of a grating spectrum given in Fig. 3-2, p. 41).
A diffraction grating has several advantages over a prism: it is independent of the dispersive characteristics of the material, the image is richer in details and the limiting magnitude of the more expensive Rowland grating is much more favourable ($M_v = 0.5$ for zero order).
The less expensive gratings are however not very sensitive and require very bright meteors to yield any results. If somebody intends to really specialize in meteor spectroscopy it is worthwhile investing in a Rowland grating. The larger cost will pay off when the grating can be used regularly.
More about meteor spectroscopy, especially procedures regarding their analysis, can be found in paragraph 4 of Part 3 (Meteor Spectra), p.40 ff..

4. Mounting and drive

Almost nothing has been said about the equipment to place the camera and the additional devices on. Generally, it is sufficient to use stable tripods for all purposes. But the photographer might wish to obtain images with the stars being points. Photography of a field with both a guided and an unguided camera allows to determine the time of a meteor's appearance. The image of a star moves over the film with an linear velocity v_s which depends on the declination δ of the star. This velocity is zero at the poles.
The linear velocity v_s of a star at a declination δ is

$$v_\mathrm{s} = \frac{2\pi f}{T_\mathrm{sid}} \cos\delta$$

with $T_\mathrm{sid} = 86164$ s the Earth's sidereal rotation period. Hence it moves by l mm within a time t [s]

$$t = \frac{l}{v_\mathrm{s}} = \frac{l\,T_\mathrm{sid}}{2\pi f\cos\delta}$$

and we find the time lapse between the beginning of the exposure and the meteor's appearance as shown in Fig. 5-8.

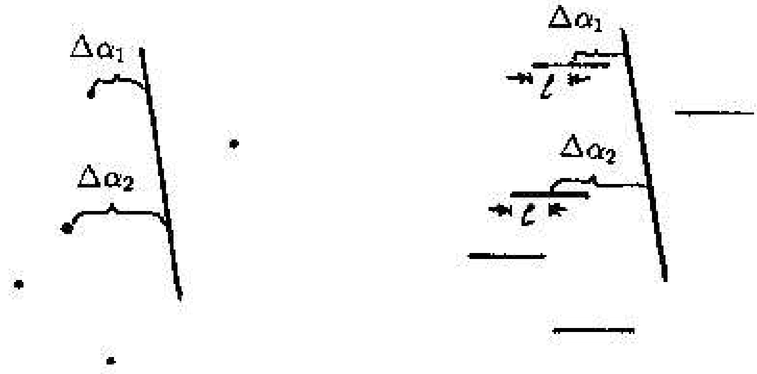

Figure 5-8: Principle of the determination of the time of a meteor's appearance from a guided (left) and an unguided (right) photography. The guided image gives the position relative to the stars, e.g. the differences $\Delta\alpha$. This difference $\Delta\alpha$ has to be applied to the unguided image. Then we may find the time passed between the beginning of the star trail and the moment the meteor appeared. (The same procedure, of course, holds for the end of the exposure.)

Sine ce the usual durartions of the exposures are of the order of hours, the mounting must be well adjusted to the north or south pole. The guiding normally has to run without control by an observer. Therefore you should have tested a mountiong and guiding system intended for meteor work before using it regularly for example for a fireball patrol station. Otherwise the stars become trails of which we do not know the moving direction during the exposure. Construction of guidings and mountings are described in many amateur astronomer's manuals and are not further outlined here.
We want to note, that such a pair of cameras – guided and unguided – is regularly used at the Ondřejov Observatory for fireball patrol, and it allows to determine the appearance of fireballs with an accuracy of some seconds (except cases where the fireball appeared at low elevation angles or in hazy skies).

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