BENTHAM

The Light Measurement Company

DMc150-MDE
Compact Double
Integrated Spectroradiometer

User Manual

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Contents

1. Introduction
This manual has been written to provide information on the use of the DMc150-MDE compact double integrated spectroradiometer and all standard options pertaining thereto.

2. Overview

The DMc150-MDE is composed of a DMc150 compact double monochromator with, situated to the base of the unit, a two-channel transimpedance amplifiers/ ADC and a high voltage supply to constitute an compact double integrated spectroradiometer.

The DMc150 in turn is composed of two 150mm focal length single monochromators operating in tandem, driven by a common grating drive.

In each component single monochromator, a kinematically mounted diffraction grating is installed. This mount permits the facile changing of gratings, maintaining the wavelength calibration.

All pairs of gratings of a given DMc150 are setup such that they share the same calibration factor, in this case the monochromator park position.

Multiple configurations are accommodated by the addition, at the entrance/ exit ports, of an additional slit with a computer-controlled selection mirror (SAM) between the two.

The entrance and exit ports can be fitted with either fixed, micrometer variable or motorised variable slits.

Figure 1:- DMc150F-U monochromator

A six- or eight-position order sorting filter wheel is situated behind the entrance port to suppress all but the first diffraction order. Included is a blank disk to act as a shutter.

All control electronics for the monochromator drive, internal filter wheel, detections electronics and SAMs are situated on the underside of the unit.

Mains and the controlling USB connections are made directly to the DMc150-MDE.

3. Grating Drive
In each half of the DMc150, is to be found a kinematic mount upon which may be installed a single diffraction grating.

The pair of grating mounts are connected by a sine-bar mechanism and driven by a stepping motor, used in the micro-stepping mode; 3000 steps per revolution of the motor turns a lead screw of 0.5mm per turn, which in turn drives a sine bar attached to the pair of gratings.

To the grating drive is fitted a two-stage encoder, allowing the unit to be sent to a fixed datum point (positive limit). On software initialisation, the turret is sent to this position, or “parked”.

The DMc150 drive being based on a mechanical sine law conversion, the wavelength scale has a sinusoidal aspect which can be corrected.

In common with all gear systems, the grating drive in the DMc150 suffers from backlash, a region of inaction immediately after the direction of rotation be changed, albeit reduced by the design of the drive. This is easily overcome by ensuring that the desired location of the turret (wavelength) be at all times approached from the same direction.

To go therefore from a higher to a lower wavelength, the turret should be moved beyond the target location which is then approached in the direction of increasing wavelength.

4. Diffraction Gratings

In each half of the DMc150 may be kinematically mounted a single diffraction grating.

The diffraction gratings for the DMc150 are 33x33mm, provided in a mount for attachment to the kinematic mount. On the former mount there exists three corner screws which are used to set the grating position and which define the grating stup/ calibration and should not be touched. Projecting from the mount is a stud which passes through the kinematic mount to permit attachment of the grating with a leaf spring fork.

On purchasing a monochromator, all gratings are factory fitted. For those gratings purchased at a later time, further information concerning grating installation is provided in § 17.

The following table summarises the maximum recommended range of use in the DMc150 of the most popular diffraction gratings offered by Bentham:-

Between zero nanometres (at which position the grating acts as a mirror) and the minimum cited wavelength, problems may be encountered with re-diffracted light whereby the zero diffraction order is coincident with the diffraction grating, and “re-diffracted”.

Above the maximum cited wavelength, the grating is rotated to such an extent that the angle of incidence of light onto the grating shall approach 90°.

Line density (g/mm)	Maximum λ range
2400	200-675 nm
1800	200-900 nm
1200	250-1200 nm
830	500-1800 nm
600	800-2500 nm
400	1- 3 μm
300	1.5-5.5 μm
150	2.4-8.0 μm
100	4.5-16.2 μm
75	6- 21 μm
50	9- 27 μm

Table 1: Grating maximum range of use

5. Grating installation
5.1 Introduction

The gratings supplied for use with the DM150 are mounted on a kinematic system which allows them to be interchanged quickly and without the loss of calibration.

On the gratings, as seen below, are screws to adapt to the kinematic mount, the positions of which have been manipulated at calibration and must not be touched. A varnish is used to ensure non removal.

Figure 2:- Diffraction grating

Gratings supplied with the instrument have been fully adjusted in manufacture and the user needs only install them as required and for critical applications, make a simple check for any shift of calibration which might have occurred in transit.

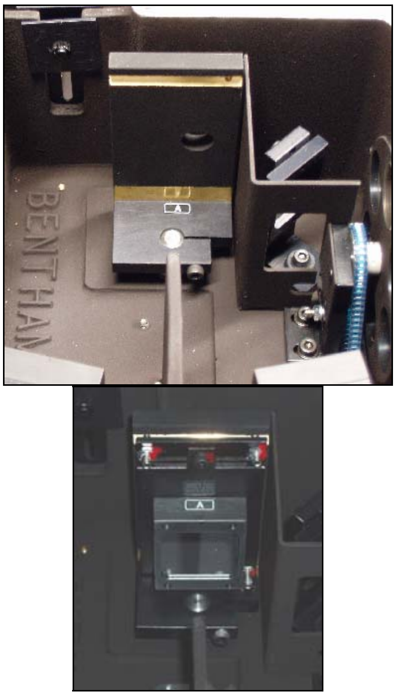
When gratings are purchased after delivery of the monochromator, the user must make simple once and for all adjustments to the new grating.

5.2 Procedure for installing gratings

Take great care not to touch the front surface of the grating, not the mirrors in the DMc150 with anything.

•Remove the lid of the Monochromator by unscrewing the six 3mm socket head screws
•Note that the gratings are position specific- on the rear of each grating is written 1A or 1B.
•Using a silk or felt glove, grasp the edges of grating A, to be installed in the entrance section of the monochromator (near to filter wheel), labelled A
•Hold the leaf spring (fork) with one hand, position the grating on its’ mount with the other.

•Pass the retaining bolt through the grating mount, and gently rock the grating to ensure in place in groove of kinematic plate



Figures 3 & 4:-Grating mount and grating in place

Figure 5:- Grating retained by leaf

•Repeat with grating B

Follow the procedure described later in §12 to check wavelength calibration of monochromator to ensure correct installation of gratings.

6. Order-Sorting Filter Wheel

The governing diffraction equation admits solutions for integer multiples of the wavelength in consideration, thus diffraction orders (see §19.7).

Most spectroradiometry is performed on the first order contribution; it is necessary to avoid measurement of higher diffraction orders for correct measurements.

A six- or eight-position order sorting filter wheel is to be found inside the monochromator entrance port, fitted with order sorting filters suitable for the spectral range of use

Below four hundred nanometres, no filters are required since for the next highest diffraction order, the second, the corresponding wavelength is less than 200nm which is blocked in any case by the atmosphere.

Spectral range	Required OS Filter
<400 m	None
400-700nm	OS400
700-1250nm	OS700
1250-2000nm	OS1250
2000-3600nm	OS2000-
3.6-6 µm	-OS3600
6-10.5 µm	OS6000
10.5-21 µm	OS10500
> 21µm	*please consult*

Table 2: Required order sorting filters

A blank disk in the last position (six or eight) stops light from entering the monochromator during dark current and offset measurements.

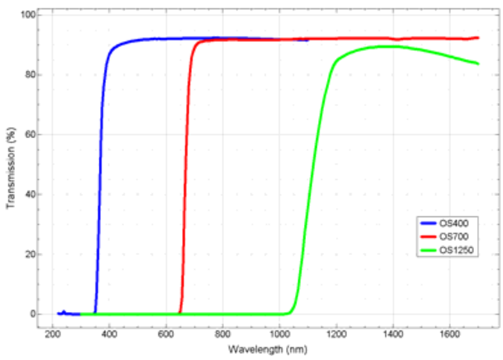


Figure 2:-Typical OS filter transmission

7. Entrance & exit slits

7.1 Introduction

The entrance and exit slits of the DMc150 can be fitted with either of the following assemblies: fixed, micrometer variable or motorised variable.

7.2 Fixed slits

Where the fixed slit option is purchased, three sets of three slits are provided according the required system bandwidth.

Fixed slit carriers incorporate a spring leaf to push the slit against its datum face to ensure the correct placement of the slit.

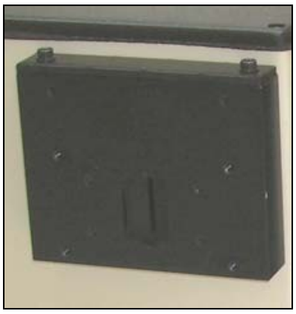


Figure 3:-Fixed slit

Changing entrance and exit slits:-

•Remove fixed slit cover with M3 Allen key
•Using pincers, pull out slit
•Place new slit in holder with ***etched side facing away*** from monochromator, ***flat rear of slit against the monochromator***
•Push fixed slit down, firmly into place
•Replace cover

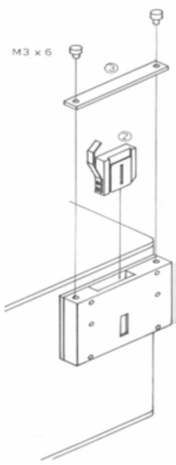


Figure 4:- Changing fixed slits

It should be noted that where a photomultiplier detector is mounted to the slit in question, the high voltage be switched off during the changing of the slit to prevent exposure to ambient lighting.

It is important that the slits are installed in the correct orientation, else a wavelength error results.

7.3 Micrometer Variable Slits

Micrometer variable slits make use of a vernier calliper controlled pair of bi-lateral slits, variable from 10μm to 10mm.

Figure 5:-Micrometer variable slit

One rotation of the calliper is equivalent to 0.5mm in slit width; the slit dimension can be read off the vernier.

To the base of the barrel a knurled nut locks the position (clockwise). This should be undone (anti-clockwise) before changing the dimensions of the slit.

Forcing the calliper beyond the zero position can result in damaging the bi-lateral slits.

7.4 Motorised Variable Slits

Motorised variable slits are comprised of stepping motor-driven bi-lateral slits, driven either from the internal monochromator electronics or from an external MAC electronics bin, and are variable from 10μm to 10mm.

Figure 6:-Motorised variable slit

Each slit should be connected to the correct drive (numbered), and all cables should be firmly attached.

Never connect or disconnect slit cables whilst MAC electronics/ monochromator powered on!

The motorised slits are entirely controlled by computer through the USB interface, please see §12.

8. Swing Away Mirrors

Swing away mirrors permit the addition of a supplementary entrance/ exit port to the DMc150, the solenoid based mirror being set to either relay the beam from one slit or to move out of the beam to use the other.

In such a manner the DMC150 may have two entrance or two exit ports.

9. Monochromator Bandwidth

The monochromator bandwidth, defined in nm, is the range of wavelengths seen by the detector at one time, and is directly linked to the monochromator slits in use.

This is an important quantity to take into account, particularly when measuring sources have fine spectral features such as line emission- for example the measurement of a source having two spectral lines one nanometre apart with a system bandwidth of five nanometres, will result in the measurement of a single line.

In many instances this is of no concern, since the power measured shall nevertheless be correct.

The effect of monochromator entrance and exit slits on monochromator bandwidth can be viewed in two manners.

In the first instance, the monochromator is an imaging system; the input port is imaged at the exit port; the dimension of the monochromator entrance slit defines the image size at the exit port.

Furthermore, at the exit of the monochromator, since the light incident thereupon is dispersed, on can imagine the wavelength axis running along parallel to the wall of the exit slit, and the size of this slit determines how many wavelengths can be seen at one time.

One can imagine therefore an infinite number of images of the entrance slit, of incrementally differing wavelength, presented parallel to the exit slit; whichever of the two are the largest, defines the bandwidth of the system.

The slit function of a monochromator provides interesting information with regards the device performance and the system bandwidth.

The slit function may be determined by the measurement of a source of narrow spectral width, such as a laser.

One should perform a measurement at smaller steps than the system bandwidth (for example 0.1nm), over a spectral range of around four times the expected bandwidth, centred on the expected wavelength of the emission line, for example 632.8nm for the HeNe laser.

The full width half maximum (FWHM) of this spectrum provides the bandwidth of the system.

Inspecting the signal at one bandwidth, two bandwidths etc. relative to the peak, provides information of the stray light performance of the system.

If the entrance and exit slits are of the same dimension, the slit function shall have a triangular profile, otherwise, the function shall be flat-topped.

It is worthy to note that care should be made in making this measurement- it is not sufficient to shine a laser in the entrance slit of the monochromator. This measurement should ideally be performed by filling the entrance slit, for example with the use of an integrating sphere, and illuminating the sphere with the source.

Finally, it follows of course that slit dimension has an impact of the light throughput of the monochromator, and in certain instances where a reduction in signal is required, either the entrance or exit slit is reduced, whilst maintaining the same system bandwidth.

It is preferable that the slit to be reduced be the exit slit to avoid any conflict with the input optic.

For information, the following table shows the bandwidth obtained for the monochromator and gratings of this system with a range of slit widths, for the single and double configurations.

It is important to remember that to perform a scan with a step size lower than the bandwidth obtained is satisfactory, on the contrary to step larger than the bandwidth results effectively in the loss of information.

Grating Groove Density (l/mm)		**2400**	**1200**	**600**	**400**	**300**	**150**	**100**	**75**	**50**
Reciprocal Dispersion (nm/mm)		1.35	2.70	5.40	8.11	10.81	21.62	32.42	43.23	64.85
Slit widths (mm)	**Part no. for pair of slits**	**Bandwidth produced (nm)**								
0.05	FS (0.05)	0.07	0.14	0.27	0.41	0.54	1.08	1.62	2.16	3.24
0.1	FS (0.10)	0.14	0.27	0.54	0.81	1.08	2.16	3.24	4.32	6.48
0.2	FS (0.20)	0.27	0.54	1.08	1.62	2.16	4.32	6.48	8.65	12.97
0.37	FS (0.37)	0.50	1.00	2.00	3.00	4.00	8.00	12.00	16.00	23.99
0.4	FS (0.40)	0.54	1.08	2.16	3.24	4.32	8.65	12.97	17.29	25.94
0.5	FS (0.50)	0.68	1.35	2.70	4.05	5.40	10.81	16.21	21.62	32.42
0.56	FS (0.56)	0.76	1.51	3.03	4.54	6.05	12.10	18.16	24.21	36.31
0.74	FS (0.74)	1.00	2.00	4.00	6.00	8.00	16.00	23.99	31.99	47.99
1	FS (1.00)	1.35	2.70	5.40	8.11	10.81	21.62	32.42	43.23	64.85
1.12	FS (1.12)	1.51	3.03	6.05	9.08	12.10	24.21	36.31	48.42	72.63
1.48	FS (1.48)	2.00	4.00	8.00	12.00	16.00	31.99	47.99	63.98	95.97
1.85	FS (1.85)	2.50	5.00	10.00	15.00	19.99	39.99	59.98	79.98	119.97
2	FS (2.00)	2.70	5.40	10.81	16.21	21.62	43.23	64.85	86.46	129.69
2.78	FS (2.78)	3.76	7.51	15.02	22.53	30.05	60.09	90.14	120.18	180.27
3.7	FS (3.70)	5.00	10.00	19.99	29.99	39.99	79.98	119.97	159.96	239.93
4	FS (4.00)	5.40	10.81	21.62	32.42	43.23	86.46	129.69	172.92	259.39
5.56	FS (5.56)	7.51	15.02	30.05	45.07	60.09	120.18	180.27	240.36	360.55
8	FS (8.00)	10.81	21.62	43.23	64.85	86.46	172.92	259.39	345.85	518.77

Table 4: Single configuration bandwidth

10. Wavelength Selection

10. Wavelength Calibration

10.1 Overview

The DMc150 was wavelength calibrated in factory.

It is recommended that the customer periodically check the wavelength calibration, particularly if the device has been transported.

The initial wavelength calibration procedure typically consists of placing a white light source on the monochromator entrance slit and finding the required grating drive position to obtain the zero order position for each grating in turn.

At this position, the white light is transmitted through to the exit of the monochromator.

This procedure represents a gross calibration, from which an be obtained a park gross park dial reading. With this information one can measure a source having known line emission to refine the calibration.

To this end a mercury lamp is typically employed, which emits a number of spectral lines in the region 250-700nm, whose position never changes.

In practice, higher diffraction orders are useful when performing wavelength calibration to provide a larger number of reference points. It is of course important to ensure that whilst observing the higher order lines, the order sorting filters of the monochromator are de-activated. This is done by setting the insertion wavelength of the non-required filters to 0nm (in Benwin+, instruments menu/ filter wheel).

The following summarises a number of the useful mercury lines. Those marked in red are particularly strong lines, leading therefore to higher orders with a measurable contribution.

1st Order	2nd Order	3rd Order	4th Order	5th Order	6th Order	7th Order
184.91						
194.17						
226.22						
237.83						
248.2						
253.65	507.3	760.95	1014.6	1268.25	1521.9	1775.55
265.2						
280.35						
289.36						
296.73						
302.15						
312.57	625.14	937.71	1250.28	1562.85		
313.17						
334.15						
365.02	730.04	1095.06	1460.08	1825.1		
365.44						
366.33						
404.66	809.32	1213.98	1618.64			
407.78						
434.75						
435.84	871.68	1307.52	1743.36			
491.6						
496.03						
546.07	1092.14	1638.21				
576.96						
579.07						
690.7						
1013.98						

Table 5: Principle Hg emission lines

10.2 Spectral Measurements

Spectral measurements are performed, the positions of these lines checked and the calibration factors, alpha and zord changed to bring the monochromator into calibration. It is recommended that the customer does not change alpha however.

Where the Hg lines are too low in wavelength, the park dial reading should be increased and vice versa.

Measurements in step of 0.1nm (with the slits in manual bandwidth mode) should be made of the regions around the Hg lines, and either the peak values or FWHM central wavelength taken as the position of the line.

Be aware of the slits presently in use in the system. Having for example 5nm slits and looking at the lines around 365nm, one will effectively see several lines which can distort the result and wrongly show lack of calibration.

In the case of infrared gratings where there is no useful emission of the Hg source, gratings are set up with the zero-order position, setting the monochromator to zero nanometres and ensuring the white light is transmitted through the exit slit.

Where a mercury lamp is not available, overhead fluorescent lamps are often of use since they contain mercury gas.

Because of the glass envelope of the lamp no light is emitted below 350nm.

Where a system contains SAMs, the calibration procedure should be repeated in all ports.

10.3 DMc150 Calibration

The calibration of the DMc150 should be performed with the smallest slits width intended to be used (where motorised slits are used, they should be in manual bandwidth mode).

Measurements should be made of a mercury source and the park dial reading modified to bring the device into calibration.

11. New Grating Installation/Calibration

11.3 Wavelength Calibration

Follow the wavelength calibration as detailed in §15.

12. Detection electronics

12.1 Components

The DMc150-MDE houses two trans-impedance amplifier/ integrating ADCs and a high voltage supply to its underside.

BNC current amplifier inputs are labelled channels 1 to 4, the HV output consists of a modified BNC output having a PTFE insert to prevent inadvertent connection of a signal cable. A on-of switch is located to the side of the port.

12.2 487 DC Current Amplifier

The 487 is used as the main amplifier in dc systems employing photodiode or photomultiplier detectors. At low frequencies such devices give their best performance when connected to this type of virtual ground input.

The input effectively has zero input impedance and hence no voltage is generated across the device as a result of the photocurrent.

This short circuit operation enhances linearity of detectors and reduces the effect of cable capacitance.

The output of the current amplifier goes directly to the ADC. The output of the current amplifier is 0-10V per range.

There exists effectively two such amplifiers in this system, number one containing inputs one and two; number two, inputs three and four.

12.3 ADC

The ADC uses a continuously running voltage to frequency converter to produce a pulse train whose frequency is proportional to the instantaneous input voltage. The pulses are accumulated in a counter.

At fixed intervals, 100ms, the contents of the counter is transferred to an output buffer and the counter reset to zero. The total number of pulses accumulated by the counter in any counting period represents the true average of the signal during that counting period.

If the accumulated pulses from a number of counting periods are added and normalised then a true average over a longer period is obtained.

The ADC has two other special features which enhance its usefulness in light measurements systems.
Firstly, the input to the ADC is offset giving the unit a small negative range. This ensures that negative going noise peaks, occurring in near zero signals, are correctly averaged while retaining most of the available resolution for positive going signals.

Secondly, the ADC provides information to the computer indicating that a transient overload has occurred at some point during the conversion period. This information is essential if accurate measurements are to be made on pulsed light sources such as CRT monitors.

The ADC provides 2000 counts per volt and has a maximum of 20000 counts.

Due to the quantum nature of light and the way in which optical detectors work, signals in light measurement systems are always accompanied by electrical noise. The limit of low light level detection is often imposed by the ability of the measuring system to distinguish between the signal to be measured and the associated electrical noise.

In most cases, where the noise is truly random, the signal to noise ratio can be improved by averaging. For a signal accompanied by random noise the signal to noise ratio will increase in proportion to $1/\sqrt{T}$ where T is the averaging period.

With dc systems the maximum period which can be used for averaging is limited by so called dc drifts (i.e. low frequency noise. The noise power in fact increases continuously as zero Hz is approached).

The ADC therefore behaves as a digital averager with the averaging period programmable in 100ms increments.

For dc systems the averaging period can be fixed for a particular experimental set-up or can be varied depending on the signal level to give a substantially constant signal to noise ratio for all signal levels. Software schemes have been used where the averaging period is determined by looking at the variance between successive readings or, more simply, by linking the averaging period to the sensitivity range of the amplifier so that averaging period increases as the sensitivity required increases.

This last approach is very useful in solar UV measurements where in a typical spectral scan from 280nm to 400nm the signal level changes by $\sim 10^6$.

Similarly, measurements which have included a transient noise pulse such as that produced by Cherenkov events in the window of a photomultiplier, can be recognised and repeated if required.

12.4 High Voltage Supply

A high voltage supply in the DMc150-MDE is provided for use with PMT and lead salt detectors, set in factory to 750V.

Connection is made to the detectors by thick BNC cable (having a connector with an insert which inhibits connecting to wrong place)

Use the flick switch to switch on; a green LED indicates HV on.

13. Setting mains voltage

The DMc150-MDE is fitted with a switch mode power supply.

Fuses are fitted dependant on location. Fuses are:-

110 V- 1260mA anti- surge
220/240V – 630mA anti- surge

14. Software Control

14.1 Introduction

The DMc150-MDE may be controlled, as part of a Bentham spectroradiometer system, with Benwin+ or by customer written applications based on the Bentham Instruments SDK.

For further details of control with the SDK, please consult the SDK manual.

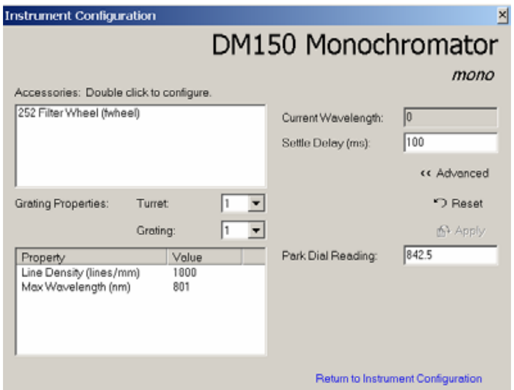
For an overview of the instrument settings in Benwin+ please see the following. For use of the software to perform spectral measurements, please consult the Benwin+ manual.

14.2 Monochromator

The properties of the DMc150 are obtained in the following menu item:-

Instruments/ Monochromator

Selecting Advanced>> gives access to the grating properties: line density and maximum wavelength.

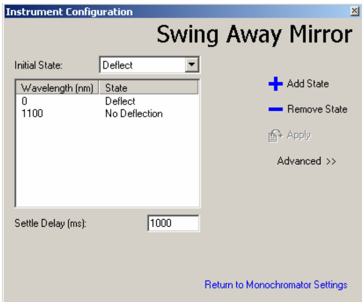


The park dial reading obtained from the wavelength calibration certificate should be input.

For USB- based systems, the settle delay can be set to 0ms. In the case of IEEE monochromators, a settle delay of 100ms is suggested.

14.3 Swing Away Mirror (SAM)

Accessed via a link in the monochromator page is the SAM page, named according to their positions.



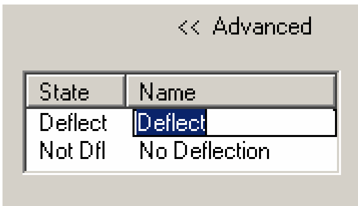
Here, one might add (“+”) a number of states (or remove by highlighting and hitting “–“).

Define states by the wavelength of insertion (inclusive), and the SAM state.

SAM states are as follows:-

•Deflect- deviate light from current path
•No deflection- move out of beam

In advanced>> can be named the two SAM states for easier setting up.

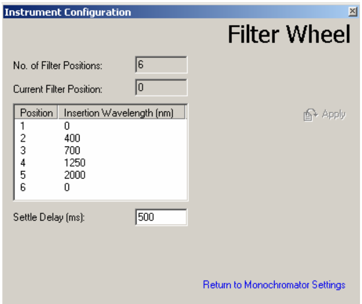


Settle delay of 1000ms is sufficient.

14.4 Filter Wheel

The properties of the filter wheel are obtained in the following menu item:-

Instruments/ Filter wheel



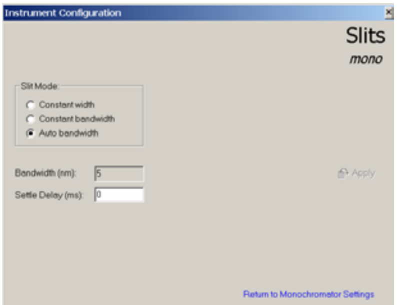
The insertion wavelength relevant to the filter in a given position should be input. The order need not be ascending.

A settle delay of 1000ms is sufficient.

14.5 Motorised slits

The properties of the motorised slits are obtained in the following menu item:-

Instruments/ Motorised slits



There are three available modes of operation:-

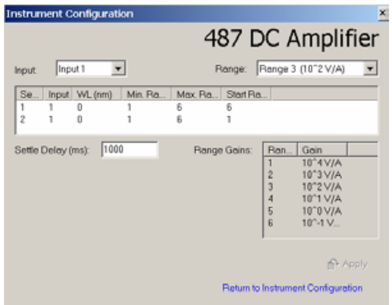
•*constant width*- input required dimension
•*constant bandwidth*- input required bandwidth
•*auto*- sets the bandwidth to the step size defined in the scan setup page

It should be noted that having calibrated a system in auto mode at a given step size, to change the step size would invalidate the calibration.

A settle delay of 100ms is sufficient.

14.6 Current Amplfier

The properties page of each DC pre-amplifier is as follows:-



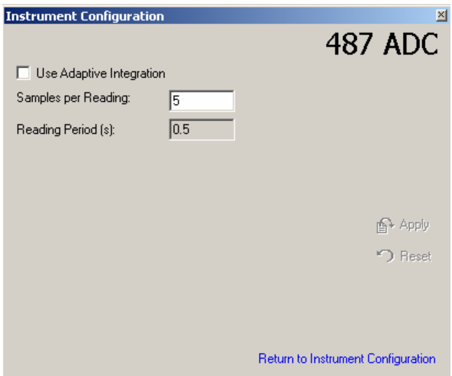
There are two setups, for which the properties may be defined. In multiple detector setups, the start wavelength of the second setup should be defined.

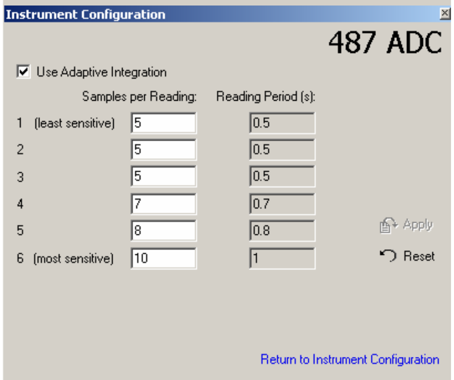
It is recommended to use all ranges 1 (min) to 6 (max). Set the start range as the max range.

A settle delay of 1000ms is sufficient.

14.7 Analogue Digital Converter

The 487 ADC integrates over 100ms periods. One can choose how many of these periods shall be taken to determine the reading at each wavelength.





A good number to use for reasonable signal is 5 averages.

One may also select adaptive integration which permits varying the number of averages taken as a function of the gain range of the current amplifier, fewer averages in the low gain ranges and more in the higher gain ranges to smooth out noise.

14.9 Configuration Files Syntax
Please consult the Benwin+ manual for further information concerning configuration file syntax.

15. System Specifications
The specifications of the DMc150 are as follows:-

XXX

16. Precautions
The following is a list of specific precautions aimed to preserve for good use this system.

•Do not touch gratings nor optics

•Do not subject monochromator to violent physical shock- this may invalidate wavelength calibration

•Do not use over-long screws when mounting items to entrance slit for fear of damaging bi-lateral slits

•Do not let the slits bear any heavy objects

17. Monochromator Operation
17.1 Introduction
The term monochrome and its variants come to us from the Greek words *mono* "single" and *chroma* "colour".

No light source is truly monochromatic; no light source emits light of a single wavelength, all sources containing contributions from a finite range of wavelengths, termed its spectrum.

It is often of interest to decompose a source into its component wavelengths, for the purpose of determining the spectral distribution (UV, visible, infrared etc), or to employ that source as a means of testing samples under "monochromatic" stimulation.

In either case, a means of wavelength dispersion is required.

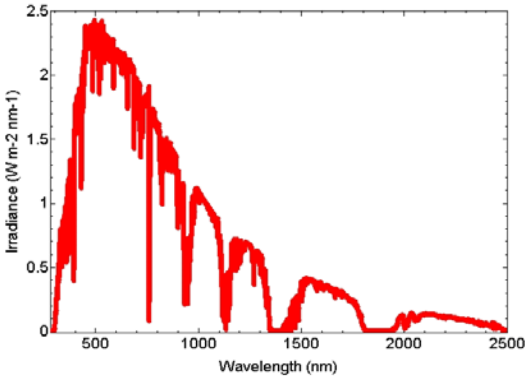


Figure 5:- Solar spectrum- from ultra violet to infrared

17.2 Light dispersion
The image of the dispersion of light can be little better conjured up than that of a rainbow.

Though not an entire description of the processes in play, the apparently "white" light from the sun, on travelling through the droplet is refracted, or bent from its path. The amount light is refracted depends upon its wavelength; blue light on one extreme of the visible spectrum is refracted more than the rest of the visible spectrum, through to red light on the other extreme, resulting in a rainbow.

In effect the sun contains wavelength components from the UV to the infra red (heat radiation), not visible to the human eye, but nevertheless part of the solar spectrum.

17.3 Light Dispersion Mechanisms
In terms of scientific instrumentation for use in the laboratory or field, the following are the principal manners of either determining the spectrum of a source.

Of the described techniques, only the reflection diffraction grating can be used over wide spectral range in a practical application, providing potentially very high spectral resolution.

It is this technique that is employed in all Bentham monochromators.

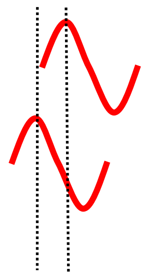
Henceforth shall be presented the theory and operation of such a device.

17.4 Wave Interference
Light can be considered as having a wave-like nature. When two such waves are brought into proximity, they interact, the resultant wave depending on the amplitudes, frequencies and relative phases of the two waves. In the context of diffraction gratings, it is sufficient to consider the case of the superposition of two waves of equal frequency (and therefore wavelength). The resultant wave is simply the sum of the two.

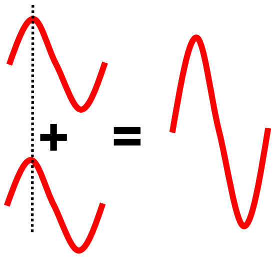
With a phase difference of zero or a whole number of wavelengths, constructive interference obtains, ie mλ where m is an integer.

With a phase difference of half a wavelength, they interfere destructively, ie mλ/2 where m is an whole number

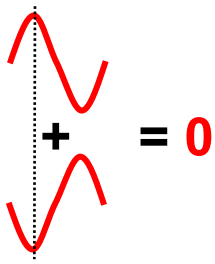
Between these two conditions varying degrees of interference result.



Phase difference



Constructive Interference



Destructive Interference

Figure 6:-Wave interference

Mechanism	***Dispersion Process***	***Pros***	***Cons***
Prism	Refraction	-Simple -Inexpensive	-Prism material absorbs light -Non-linear dispersion
Reflection diffraction grating	Diffraction	-Can be optimised	-Linear dispersion -Complex process -Delicate optics -Expensive -Delicate optics
Transmission diffraction grating	Diffraction	-Relatively simple	-Linear dispersion -Complex process -Delicate optics -Expensive -Grating material absorbs light
Band Pass Filter	Band pass filters	-Simple -Relatively inexpensive (in visible-NIR only)	-Low spectral resolution -Low throughput

17.5 Theory of diffraction
Diffraction describes a variety of processes which obtain when waves, such as light, approaches an obstacle of dimension of the order of their wavelength, and is characterised by the apparent bending of the waves around the object, such as is demonstrated overleaf.

What is transmitted in the one case is a sharp image of the aperture, and in the other a diffracted image of the aperture (seen , whereby most of the light is transmitted on axis, but at wider angles, because of interference effects, a diffraction pattern obtains.

Whilst this example demonstrates the principle in transmission, the same applies were the aperture replaced by a reflecting surface; would be reflected in the case of a narrow mirror light would be reflected in all directions. Note that in the case of reflection, specular reflection obtains, where the peak in intensity is transmitted in the same angle as the angle of incidence.

This is termed single slit diffraction.

17.6 Reflection Diffraction Grating
A reflection diffraction grating is a surface which, on the microscopic scale, is made up of a large number of rectangular grooves of width comparable to the wavelength of light to be considered. Bentham uses gratings with a “groove density” from 75- 2400 grooves per millimetre.

On shining light upon this surface, diffraction at each of the grooves obtains; each groove acting as a (coherent) source of light, emitting a cylindrical wave.

The coherence of these cylindrical waves is an important aspect since any phase difference between adjacent grooves is due solely to geometry and not from the source.

It is the interference of the light from these numerous sources that is of interest.

Diffraction can be visualised by the following, whereby light of wavelength λ is incident at an angle α to the normal of a diffraction grating of groove spacing, d. Light is diffracted along angles β_m into a number, m, of diffraction orders.

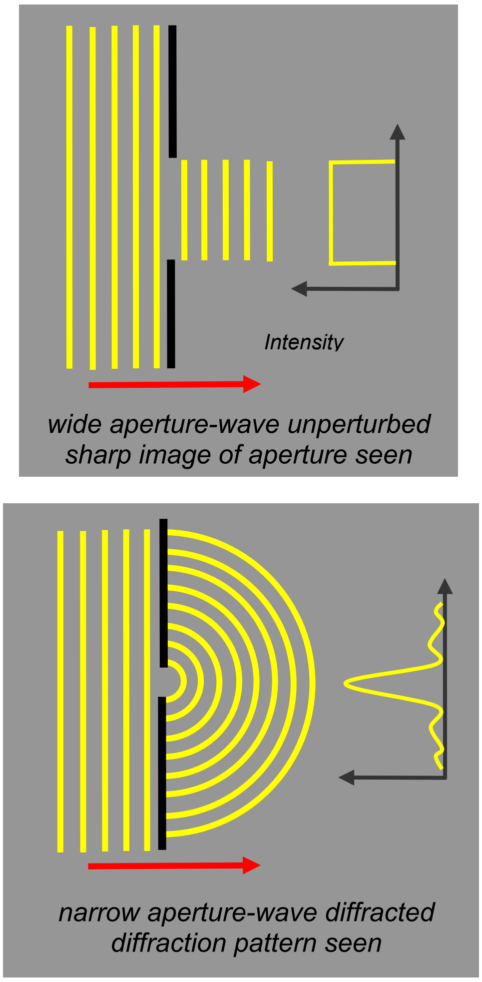


Figure 7:-Single slit diffraction

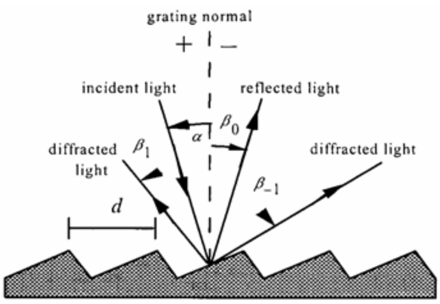


Figure 8:- Plane reflection grating diffraction

It is the interference between the waves diffracted from each groove the provides wavelength discrimination as a function of angle.

A sign convention exists for the definition of angles and orders. In general angles are measured from the grating normal to the incident wavefront.

Should diffraction occur on the opposite side of the grating normal, then negative angles are used.

This view can be simplified to the following, where one can consider two adjacent grooves separated by a distance, d.

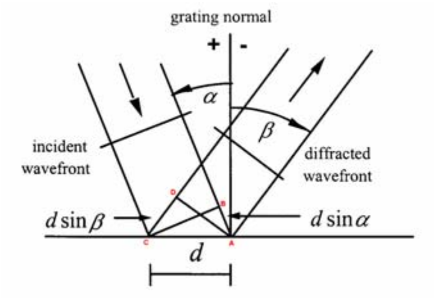


Figure 9:- Path difference between neighbouring rays

The geometrical path difference, Δ, between the path of the incident wavefront between A and B and the diffracted wavefront between C and D is

$$\Delta = AB + CD = d \sin \alpha + d \sin \beta \ldots\ldots 1$$

Now, for constructive interference to obtain, adjacent rays must differ by integer number of wavelengths. This leads to the grating equation.

$$m\lambda = d(\sin\alpha + \sin\beta) \ldots\ldots. \quad 2$$

or

$$Gm\lambda = \sin\alpha + \sin\beta \ldots\ldots.. \quad .3$$

where G is the groove density, G= 1/d.

For a given incidence angle α, there shall therefore be a set of discrete angles for which constructive interference shall be observed. At all other angles, there will be some measure of destructive interference.

Here m is the diffraction order and is an integer.

Since the absolute value of the sine function cannot exceed unity, then:-

$$| m\lambda / d | < 2 \ldots\ldots\ldots\ldots.. \quad .4$$

For a particular wavelength the above gives the possible diffraction orders present.

Specular reflection (α =β) always exists, this is the m=0, zero order position, where the grating simply acts as a mirror and the component wavelengths of the incident wavefront are not separated.

In Bentham monochromators, the grating is rotated as a function of wavelength, about a pivot coincident with the central ruling, to scan through wavelengths. The direction of the incident and diffracted light remains therefore unchanged.

In this case, one refers to the angular deviation, 2K, between the incidence and diffraction directions, defined as:-

$$2K = a - \beta = \text{constant} \qquad 5$$

Further defined is the scan angle, φ, measured from grating normal to the dissector of the beams

$$2\varphi = a + \beta \ldots\ldots\ldots\ldots\ldots\ldots 6$$

Now, substituting, the grating equation becomes:-

$$m\lambda = 2d\cos K \sin\varphi \ldots\ldots 7$$

For a given monochromator K is a constant, therefore one can determine select a wavelength by determining the required grating angle.

17.7 Diffraction orders

As noted above, the grating equation may be satisfied at a given angle by a number of wavelengths of different diffraction orders.

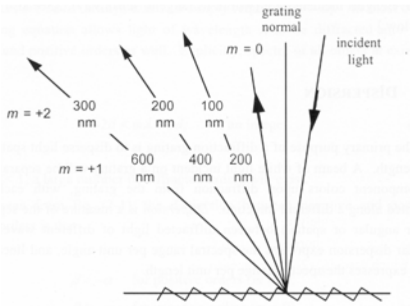


Figure 10:- Existence of diffraction orders

This can lead to problems when attempting to measure light in a given diffraction order, when the detection system is capable of sensing the wavelength in the next diffraction order etc.

Order sorting is therefore required, and consists of the filtering of the monochromator input with long pass filters where higher diffraction orders might be present.

This also leads to on explanation for measurement in first order. The wavelength of light that diffracts along the direction of λ_1 in order m+1, is $\lambda_1+\Delta\lambda$, where

$$\lambda_1 + \Delta\lambda = \frac{m+1}{m}\lambda_1 \quad \text{............8}$$

Hence we define the free spectral range, the range of wavelengths over which overlapping of adjacent orders does not occur,

$$F_\lambda = \Delta\lambda = \frac{\lambda_1}{m} \quad \text{............9}$$

17.8 Diffraction grating production

Gratings found in monochromators are replicas based on master gratings.

Master diffraction gratings are produced by one of two means:-

-Holographic exposure then chemical etch of grooves
-Mechanical ruling of grooves

In the holographic technique a substrate is covered with a photoresist material whose properties change under light stimulation.

Exposure to an interference pattern defines the grating outlay, chemical etching is then employed to selectively etch the substrate as a function of the photoresist.

This method produces almost sinusoidal grooves, but of very high surface quality.

The mechanical technique involves the mechanical inscribing, using a diamond tip in a “ruling engine” to define grooves on a metal substrate, a lengthy and difficult process.

This method yields very good, triangular grooves, resulting in gratings of very high efficiency. However, surface defects may have an impact in certain cases by introducing stray light into the monochromator.

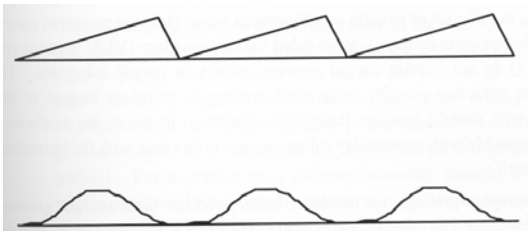


Figure 11:- Groove shape obtained using ruling (upper) and holographic techniques

Replica gratings are resin casting of master gratings, on a glass substrate, which are then coated by a suitable metallic coating for the spectral range of use, such as aluminium.

Diffraction gratings may be produced on flat (plane) or non-flat (for example concave) substrates.

17.9 Diffraction grating efficiency

The efficiency of a grating is defined as the power of monochromatic light diffracted into a given order relative to that light incident.

In order to increase the efficiency of a grating at a given wavelength, the angle of the grooves is designed such that the specular reflection from the grating surface lies in the same direction as that wavelength in question.

This procedure is called blazing, the peak wavelength being the blaze wavelength.

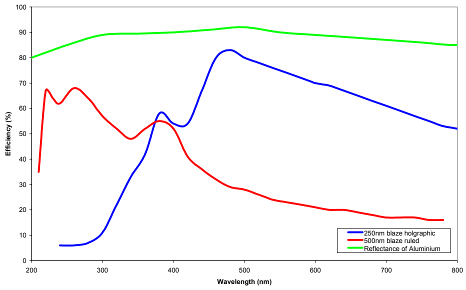


Figure 12:- Example grating efficiency curves

The consideration of grating efficiency becomes more complicated when one considers polarised incident light, and in particular the case of TM polarised light in which case the electric field vector is perpendicular to the grooves, giving rise to anomalies, or abrupt changes in the grating efficiency curve.

17.10 Czerny-Turner Monochromator

The Czerny-Turner configuration, as employed in Bentham monochromators, uses a plane diffraction grating.

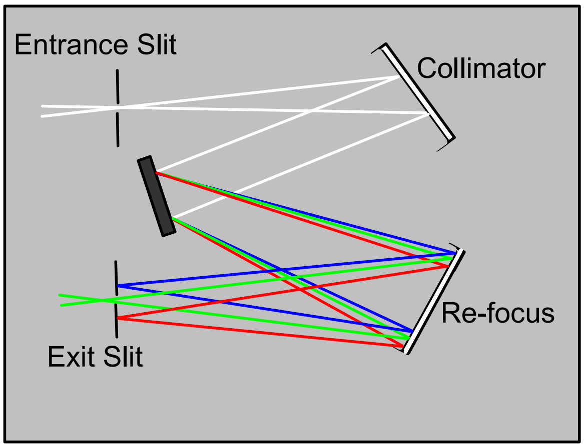


Figure 13:- Czerny-Turner configuration

In order to control the location of diffracted light, the grating should be illuminated by collimated light.

Incident light, diverging from an entrance slit is collimated by a first concave mirror. After diffraction from the grating, light is focussed to an exit slit by a second concave mirror.

As a function of wavelength therefore, the grating is rotated to scan through a spectral range.

17.11 Stepping motor drives

It has been seen that in fixed angle monochromators, it is of question to move the diffraction grating through a range of angles in a repeatable manner. To this end, stepping motors are employed.

A stepper motor is a type of electric motor that moves in increments, or steps, rather than turning smoothly as a conventional motor does. The size of the increment is measured in degrees and can vary depending on the application.

Typical increments are 0.9 or 1.8 degrees, with 400 or 200 increments thus representing a full circle. The speed of the motor is determined by the time delay between each incremental movement.

Inside the device, sets of coils produce magnetic fields that interact with the fields of permanent magnets. The coils are switched on and off in a specific sequence to cause the motor shaft to turn through the desired angle. The motor can operate in either direction.

When a current is passed through the coils of a stepper motor, the rotor shaft turns to a certain position and then stays there unless or until different coils are energized. Unlike a conventional motor, the stepper motor resists external torque applied to the shaft once the shaft has come to rest with current applied. This resistance is called holding torque.

Stepping motors, combined with gear systems or sine-bar mechanisms are used to provide high precision and highly repeatable monochromators.

17.12 Double monochromators

When using a single monochromator such as that shown in figure 13, it is possible that light, entering from the entrance slit, be scattered off the walls and structures constituting the monochromator, reach the exit slit.

Therefore, at a given wavelength, λ, an artificially high signal is measured.

This is termed stray light and is of concern where low light level measurements are performed where there exists a significant light component at other wavelengths.

Classical examples are measurements of UV sources and high optical density filter transmission.

Consider for example the measurement of a quartz halogen lamp, a lamp often used as calibration standard.

The following figure demonstrates the effect of scattered light in measuring the lamp UV output where there exists a significant amount of visible light.

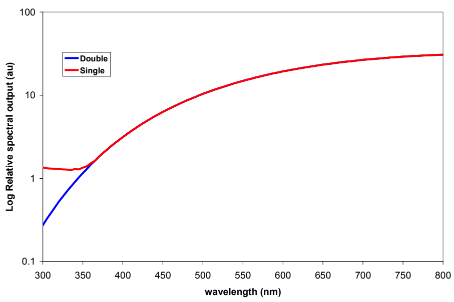


Figure 14:- Measurement of QH lamp with single and double monochromators

A double monochromator situates a second single monochromator at the exit of the first.

Entering the first monochromator is all the light from the source to be measured; entering the second monochromator is the wavelength selected and a level of stray light, which one desires to reduce.

In the second monochromator, the desired wavelength re-selected; at the exit slit one finds that the level of the stray light has reduced to the square of the case of the single, for example a factor 10^4 down in a single, a factor 10^8 down in a double.

There are two possible configurations of double monochromator; with additive or subtractive dispersion.

With additive dispersion, the first monochromator is followed by a device of similar type.

The band of light transmitted from the first to second is further dispersed, resulting in twice the dispersion of a single system; for a given required bandwidth therefore, the monochromator slits may be doubled in size with respect to a single monochromator, which increases the system throughput.

With subtractive dispersion, the second monochromator is operated in an inverse manner to the first in such a manner that at the exit slit there exists no net dispersion. At the exit of the first monochromator, the light to be transmitted to the second monochromator is dispersed across the slit; at the exit of the second monochromator this dispersion does not exist and all the wavelengths are combined.

The dispersion of a subtractive double monochromator therefore is the same as that of a single monochromator.

The subtractive configuration is often employed in such systems as primary transfer standard where the uncertainty of dispersion across the detector slit is unacceptable (yet for most applications of no real consequence).

A further important point is that of the slits of the double monochromator. With additive dispersion, it is the entrance and exit slits which define the system bandwidth, the middle slit between the two monochromators being employed to reduce the stray light being transmitted to the second element. The middle slit should be at least twenty percent larger than the largest slit of the system to prevent tracking problems (beating) between the two component monochromators.

With subtractive dispersion, it is the entrance and middle slits which define the system bandwidth; the exit slit is employed to reduce the system stray light and again should be at least twenty percent larger than the largest slit of the system.

Product Guarantee

BENTHAM INSTRUMENTS warrants each instrument to be free of defects in material and workmanship for a period of **one** year after shipment to the original purchaser. Liability under this warranty is limited to repairing or adjusting any instrument returned to the factory for that purpose.

The warranty of this instrument is void if the instrument has been modified other than in accordance with written instructions from BENTHAM, or if defect or failure is judged by BENTHAM to be caused by abnormal conditions of operation, storage or transportation.

This warranty is subject to verification by BENTHAM, that a defect or failure exists, and to compliance by the original purchaser with the following instructions:

1. Before returning the instrument, notify BENTHAM with full details of the problem; including model number and serial number of the instrument involved.

2. After receiving the above information, BENTHAM will give you shipping instructions or service instructions. After receipt of Shipping instructions, ship the instrument “carriage paid” to BENTHAM. Full liability for damage during shipment is borne by the purchaser. It is recommended that instruments shipped to us be fully insured and packed surrounded by at least 2 inches of shock-absorbing material. Specific transit packaging as used in monochromators etc. must be installed.

BENTHAM reserves the right to make changes in design at any time without incurring any obligation to install same on units previously purchased.

This warranty is expressly in lieu of all other obligations or liabilities on the part of BENTHAM, and BENTHAM neither assumes, nor authorises any other person to assume for it, any liability in connection with the sales of BENTHAM’S products.

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