

AN OPTICAL APPARATUS AND METHOD

This invention relates to an optical apparatus and method. In particular, the invention relates to an optical apparatus comprising at least one liquid
5 lens or flexible membrane mirror, and more particularly to a pair of spectacles constituted by or including such an apparatus.

The invention also relates in particular to a method of adjusting an optical apparatus for correcting defective eyesight.

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It is known to provide a liquid lens in the form of one or more transparent, circular, flexible membranes clamped about a peripheral zone to define a cavity. The cavity is filled with a transparent liquid, the pressure of which is adjustable by means of a positive displacement pump
15 such as a syringe.

Adjustments of the pressure of fluid in the cavity cause variations in the curvature of the lens defined by the membranes and fluid, thereby giving rise to a lens of infinitely variable optical power.

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US Patent No. 4,890,903 gives further details of liquid lenses, and of optical instruments such as spectacles incorporating such lenses. The entire disclosure of US Patent No. 4,890,903 is incorporated herein by reference.

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The history of liquid lenses goes back several decades, yet there has not previously been a proposal for a truly practical sight-correcting device incorporating such lenses.

30 According to a first aspect of the invention, there is provided an optical

apparatus comprising:

at least one liquid lens or flexible membrane mirror;

a liquid pump for adjusting the pressure of liquid in the or a cavity of the lens or mirror;

5 a closeable duct for interconnecting the said cavity and the pump permitting the flow of liquid therebetween; and

a closure for closing the duct when the pressure of liquid in the said cavity attains a desired value, whereby to render the lens or mirror subsequently non-adjustable.

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The principal advantage of such an arrangement over previous apparatuses is that the liquid lens or lenses become non-adjustable after adjustment of the lens or lenses to a desired setting. This is in contrast to previous apparatuses, in which the liquid lenses have remained perpetually
15 adjustable. Thus, previous liquid lens apparatuses could not be incorporated into spectacles partly because of the cumbersome nature of the pumps needed for adjustment of the lenses; and partly because of the risk of the optical power of the lenses deviating from optima tailored for the wearer of the spectacles.

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Thus, an apparatus according to the invention confers a robustness and practicality not achievable with previous liquid lens designs.

Preferably the closure includes a portion of the duct plastically deformable
25 to close the duct. In particularly preferred embodiments, the duct is plastically deformable when compressed and or when heated. A further possibility is for the duct to be plastically deformable when subjected to ultrasonic excitation.

30 The foregoing features mean that apparatus according to the invention can

readily be adjusted to a preferred optical power of the lenses, and easily set at the preferred optical power.

Conveniently, the pump is a positive displacement pump capable of
5 increasing and decreasing the pressure of liquid in the cavity. In particularly preferred embodiments, the pump is a syringe.

Syringes are mass-produced at extremely low cost, and therefore they provide a simple, inexpensive means of setting the power of the lenses of
10 an apparatus according to the invention, eg. in a harsh environment.

In some embodiments of the invention, the closure preferably includes a member retentively deformable to close the duct. One form of such a member is a resiliently deformable bung closing the duct. For use with
15 such a bung, the pump may include or be operatively connected to a further duct capable of removably piercing the bung to permit the flow of liquid between the pump and the cavity, the resilience of the bung (a) creating a liquid-tight seal about the further duct when the bung is pierced thereby; and (b) causing closure of the aperture pierced by the further duct
20 on removal thereof from the bung.

In particularly preferred embodiments, the further duct is a hollow needle.

Thus it is possible to devise embodiments of the invention in which the
25 pump is a conventional syringe having a conventional hypodermic needle secured thereto, in order to pierce a resiliently deformable bung that re-sealably closes the duct of the apparatus.

Yet a further possibility for closing the duct is for the retentively
30 deformable member to include opposed, interior walls of the duct capable

of sealingly adhering one to another on compression of the duct. In preferred embodiments, this is achieved by virtue of adhesive matter secured on the opposed, inner walls of the duct.

- 5 Using this embodiment, it is possible advantageously to seal the duct without employing any additional components, other than a simple apparatus such as a pair of pliers or pincers to compress the duct.

The invention is also considered to reside in a pair of spectacles including
10 an apparatus as defined hereinabove, the apparatus preferably including a pair of liquid lenses.

The advantageous features defined hereinabove in relation to the apparatus are of particular benefit when the apparatus is incorporated in a pair of
15 spectacles. In particular, spectacles according to the invention provide the possibility of correction of many eyesight defects, without the need for a skilled optometrist in assessing the optical power of the lenses required for such correction. This in turn makes the spectacles particularly suitable for use in so-called developing countries, where the incidence of various
20 eyesight defects is high yet there are few skilled opticians and very little equipment for testing of eyesight in conventional ways.

Furthermore, since spectacles according to the invention can be manufactured in large numbers without the need for variation between
25 different pairs of spectacles at the manufacturing stage, the purchase price of spectacles according to the invention can if desired be made sufficiently low to enable their purchase by inhabitants of developing countries or by charities providing aid in such countries.

30 Conveniently the pair of spectacles includes a respective liquid pump and

a respective closable duct for each lens. These features advantageously permit employment of an inventive method of adjusting the spectacles for correcting eyesight defects, as defined hereinbelow.

- 5 Preferably the or each closable duct is flexible and the frame of the spectacles includes one or more recesses for receiving the or a duct after closing thereof. More preferably, the or each recess is closable to conceal the closed ducts. This permits the construction of an aesthetically pleasing pair of spectacles, in which the closable ducts are protected from damage.

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- In practical embodiments of the spectacles according to the invention, each lens includes a rigid, transparent cover for protecting a flexible membrane of the lens. Optionally, the or each transparent cover has an optically corrective effect. Multiple protective covers may be supplied if desired,
15 eg. on the front and rear face or each liquid lens of the spectacles, in order to protect the lenses against damage.

- If one or more of the protective covers has an optically corrective effect, a number of advantages may inure to spectacles according to the
20 invention. For example, the protective covers may provide a degree of inherent correction in the spectacles regardless of the pressures in the liquid lenses, thereby conveniently limiting the range of adjustment of the liquid lenses required to provide improvements in eyesight for the majority of users of the spectacles.

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- Also, although it is possible to construct liquid lenses that have a concavo-convex shape, it is far simpler to construct liquid lenses of convex lens shape. Such lenses do not provide correction for conditions such as astigmatism. The protective covers may, particularly if present at the
30 front and rear faces of the liquid lenses, be shaped to provide correction

for such conditions thereby obviating the need for the liquid lenses to provide correction for conditions other than myopia and presbyopia.

Optionally the or each transparent cover has an optical filtering effect.

5 Thus it is possible in accordance with the invention to manufacture eg. corrective sun glasses and welding masks.

Preferably the optical apparatus also includes one or more compound, fluid lenses. Further details of such lenses are provided in the
10 aforementioned US Patent No. 4,890,903.

Embodiments of apparatuses, including spectacles, in accordance with the invention may optionally be such that the or a fluid lens thereof contains a predetermined quantity of liquid, the pump thereof being capable of
15 adjusting the fluid pressure in the lens cavity in a limited range. Thus it would be possible to manufacture and supply spectacles having a predetermined quantity of fluid in each lens, and simply connect the pump, including a small reservoir of the fluid, to each lens at the point of use, ie. when it is required to adjust and set the spectacles for use by an
20 individual. This avoids the need for the pump to include a sufficiently large supply of liquid to fill the lens from empty, although such lens and pump combinations are considered to be within the scope of the invention.

According to a second aspect of the invention, there is provided a method
25 of adjusting an apparatus for correcting defective eyesight, comprising the steps of:

- (i) placing an apparatus as defined hereinabove in front of a patient's eye such that the eye receives light through the or a lens thereof;
- (ii) operating the pump of the apparatus until the patient sees an
30 optimum clarity image;

- (iii) closing the duct of the apparatus; and
- (iv) detaching the pump from the apparatus.

Desirably, the patient views a distant object during step (ii).

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This method is particularly suitable when the apparatus is configured as eg. a monocle or similar device intended for use by one eye only of a patient. Thus this aspect of the inventive method is particularly suitable for patients who have sight in only one eye, a condition common in many
10 developing countries.

According to a third aspect of the invention, there is provided a method of adjusting an apparatus for correcting defective eyesight, comprising the steps of, in any practical order:

- 15 (i) placing a pair of spectacles as defined hereinabove in front of a patient's eyes so that each of the patient's eyes receives light via a respective lens of the spectacles;
- (ii) obscuring the pupil of a first of the patient's eyes;
- (iii) operating the pump of the lens associated with the second of
20 the patient's eyes until the said second eye sees an optimum clarity image;
- (iv) closing the duct between the said lens and its associated pump;
- (v) uncovering the pupil of the first eye;
- (vi) obscuring the pupil of the patient's second eye;
- 25 (vii) repeating steps (iii) and (iv), *mutatis mutandis*, with respect to the patient's second eye; and
- (viii) detaching the or each pump from the apparatus.

Desirably step (iii) is carried out each time while the patient views an
30 object, which may be either distant or proximal.

This aspect of the inventive method is suitable for patients having the use of both eyes, one or both of which require correction.

Conveniently, when the spectacles include a recess as defined hereinabove,
5 the method may include the further steps of:

(ix) after closing, placing each duct in a recess of the spectacles;

and

(x) covering the or each recess.

10 Thus it will be seen that the apparatuses and methods of the invention provide a convenient, cheap and rapid means of correcting eyesight through use of monacles and spectacles. However, the ability to set the power of the liquid lens deriving from the invention is not limited to applications in which correction of defective sight is required. Further
15 exemplary applications include adjustment of convex mirrors provided for security in shops and for safety purposes at difficult road junctions; focusing of light beams eg. for use in illuminating buildings, either through use of fluid lenses or flexible membrane mirrors; and numerous other occasions when it is required to tailor the optical power of a lens or
20 mirror to a particular requirement and set the optical power so that it is subsequently non-adjustable.

There now follows a description of preferred embodiments of the invention, by way of example, with reference being made to the
25 accompanying drawings in which:

Figure 1 is a partly sectioned view of a pair of spectacles manufactured in accordance with the invention;

Figure 2a is a cross section on line 2-2 of Figure 1 showing details
30 of the securing arrangement for the membranes of the lenses;

Figure 2b shows a portion of the Figure 2a arrangement in more detail;

Figure 3 shows one form of re-sealable closure for the duct of the spectacles of Figure 1;

5 Figure 4 shows another form of closure; and

Figure 5 shows a pair of spectacles incorporating the Figure 4 embodiment.

Referring to the drawings, there is shown a pair 10 of spectacles in accordance with the invention. As is best shown in Figure 1, the spectacles 10 include a pair 11a, 11b of liquid lenses each of which may generally be of the kind disclosed in US Patent No. 4,890,903. The lenses 11a, 11b are secured in a frame 12 shaped in the conventional manner of spectacles, and including a bridge 12a and a pair of side arms 12b (one of which is visible in Figure 1) secured to the frame 12 in a conventional manner eg. through use of rivets or screws 13.

As is best shown in Figures 2a and 2b, the frame 12 is in the vicinity of each lens 11a, 11b a laminar structure having a top plate 14, a bottom plate 16 and a middle plate 17 sandwiched between the top and bottom plates. A pair of flexible, transparent membranes 18, 19 (eg. of 23 micron thickness type D "Mylar" (RTM) material) are secured respectively between the middle plate 17 and the upper plate 14; and between the middle plate 17 and the lower plate 16, to define a liquid lens cavity 20.

The membranes 18, 19 are circular, and the plates 14, 16, 17 include a circular series of aligned apertures 22 for receiving eg. set screws 23 for clamping the membranes 18, 19 between the plates.

Each aperture 22 in the bottom plate 16 may be suitably tapped for engagement with the threaded end of a set screw 23.

As is best shown in Figure 2b, the membranes 18, 19 are clamped by virtue of opposed O-rings 24 in the manner described in US Patent No. 4,890,903. This arrangement ensures that each membrane experiences a radially outwardly directed tension.

The components of Figures 2a and 2b are shown spaced apart, but in use of the apparatus would of course be clamped tightly together by virtue of the screws 23.

As is shown in Figure 1, the cavity 20 of each lens 11a, 11b is connected to a filling duct 24 passing through a portion of intermediate plate 17. Filling duct 24 opens into a recess 25 that is open-ended on the exterior of the frame 12 of the spectacles 10. Recess 25 is capable of sealingly receiving eg. a filler tube for the transparent liquid intended to fill the lens. Thus, filling of each lens is possible via its associated recess 25 and filler duct 24.

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The Figure 1 embodiment shows a valving member 27 comprising a shaft 27a having a through-going aperture 27b that is alignable with the longitudinal axis of duct 24 in order to permit flow of fluid along duct 24. Shaft 27a is rotatable by virtue of knurled ring 28 in order to rotate aperture 27b out of alignment of the longitudinal axis of duct 24, thereby closing the duct when desired.

The spectacles of Figure 1 include a further, threaded recess 29 extending between a peripheral edge of the middle plate 17 and a further duct 30 also connected to the cavity 20 of each lens 11a, 11b. A threaded plug 31

is sealingly insertable into recess 29, in order selectively to seal duct 30. The presence of duct 30 and recess 29 permits the expulsion of gas from cavity 20 during filling thereof. After filling, plug 31 is used to close duct 30 against leakage of liquid.

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Although the spectacles of Figure 1 are highly effective in correcting defective vision, they are likely, by virtue of the valving member 27, plug 31 and generally heavy design of the frame 12, to be regarded as unacceptably cumbersome by potential wearers. The embodiments of
10 Figures 3 to 5 therefore serve to make the spectacles lighter and more aesthetically appealing.

It is envisaged that production embodiments of the spectacles would be supplied with the lens cavities 20 pre-filled with a predetermined volume
15 of transparent liquid. Since the pre-filling would be carried in a factory environment, the duct 30 could, after filling, be sealed permanently, eg. by welding, insertion of a settable material or by screwing a flush-fitting plug into a threaded aperture similar to recess 29. Therefore, mass produced versions of the spectacles would dispense with the plug 31 *per se*
20 thereby lightening the spectacles and making them more pleasing aesthetically.

In the Figure 3 embodiment, the valving member 27 and the recess 25 are dispensed with. Instead, each duct 24 includes a portion 24a that is of
25 enlarged diameter in order snugly to receive a resiliently deformable bung 33 that normally seals duct 24 in a liquid-type manner.

When it is required to adjust the pressure in cavity 20, a hypodermic-type needle 34, operatively secured to a syringe 35 serving as a positive
30 displacement pump for the transparent liquid (eg an inert silicone oil) is

inserted into duct 24 so as completely to pierce bung 33, thereby providing a fluid communication path between syringe 35 and cavity 20. During this process, the resilience of the material of bung 33 causes bung 33 to seal about needle 34 in a liquid-tight manner, thereby preventing
5 leakage of liquid from the cavity 20.

After adjustment of the pressure in cavity 20, by virtue of movement of the piston of syringe 35, needle 34 is withdrawn from bung 33. The resilience of bung 33 causes the aperture previously formed by needle 34
10 to self-seal, thereby closing duct 24 in order to prevent further adjustment of the optical power of the lens 20.

If desired, a suitable cap may be inserted into the upper end 24b of duct 24, in order to prevent in the ingress of dirt, etc.

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An alternative arrangement is shown in Figure 4. In this embodiment, duct 24 opens into an enlarged-diameter portion 36 that itself opens into an elongate recess 37 formed as a depression in the outer surface of the middle portion 17 of frame 12.

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Enlarged-diameter portion 26 contains seated therein in a conventional manner an O-ring grommet 38 that serves to retain a flexible, hollow tube 39. Grommet 38 seals around tube 39 and around the interior of enlarged diameter portion 36 in a liquid-tight manner, so that tube 39 is capable of
25 communicating liquid, via duct 24, and from cavity 20. Alternatively, tube 39 may be bonded directly e.g. to duct 24, thereby obviating the need for grommet 38.

The free end 40 of tube 39 may be connected to a positive displacement
30 pump such as syringe 35 for adjustment of the pressure of liquid in the

cavity 20. After adjustment of the liquid pressure in order to achieve a desired dioptré setting of the lens 20, the tube 39 is sealed by virtue of a pair of jaws 42 being moved towards one another to seal tube 39.

- 5 Tube 39 may be such as to deform plastically under the influence of heat, pressure and/or ultrasonic excitation. Jaws 42 may be such as to supply such forms of energy to tube 39 when jaws 42 are brought into contact with opposed sides of tube 39.
- 10 One particularly preferred form of the jaws 42 that may be of benefit in developing countries is a pair of jaws 42 heated by virtue of a propane burner that would cause plastic, sealing deformation of tube 39 when the jaws 42 are brought together about tube 39.
- 15 Numerous other methods of sealing tube 39 are possible, for example a constricting collar may be applied to tube 39. Also, alternative methods of securing tube 39 in enlarged-diameter portion 36 may be employed.

20 After sealing of tube 39, it is tucked into recess 37. A cover 43 may be snap-fitted to the exterior surface of frame 12 as shown in Figure 5, in order to provide an aesthetically pleasing appearance to the spectacles 10.

25 The Figure 5 embodiment also shows schematically, in dotted lines, a pair of rigid, transparent covers 44, 45 secured respectively on either side of each lens 11a, 11b in order to prevent damage to the lenses. If desired, as previously discussed, the covers 44, 45 may have optically corrective and/or filtering properties.

30 In practice, the covers 44, 45 may be contained within the "envelope" defined by the profile of the frame 12, in order to provide an aesthetically

pleasing appearance to the spectacles. Alternatively, the covers 44, 45 may be retained by virtue of slots or clips on the exterior of frame 12.

There now follows a description of a method of adjusting apparatus for
5 correcting sight defects, in accordance with the invention.

As previously mentioned, the spectacles are likely to be supplied pre-filled with a suitable transparent fluid. The wearer puts the spectacles on, closes one eye and adjusts the pressure of liquid in the lens in front of the
10 other eye whilst looking at e.g. a distant or proximal object so as to achieve sharp focus for that eye. The wearer then closes the eye previously open, and opens the eye previously closed. He then adjusts the pressure of liquid in the lens in front of the now open eye, whilst looking at distant object to achieve sharp focus for that eye.

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At suitable points in the procedure (after each lens has been set to a desired pressure) the ducts 24 for the respective lenses are closed by one of the methods disclosed herein, thereby rendering the lenses of the spectacles subsequently non-adjustable.

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If the embodiment of Figures 4 and 5 is used, after closing of the duct 24 the cover 43 is applied to the recess 37 for each tube 39.

A simplified procedure may be adopted when it is required only to correct
25 the vision of one eye of a user of apparatus in accordance with the invention. The simplified procedure involves looking through an apparatus according to the invention and having at least one liquid lens, whilst looking at a distant object. The pressure of liquid in the lens is then adjusted in order to achieve sharp focus for the eye the eyesight of
30 which is being corrected. Subsequently, the duct 24 of the apparatus is

closed in accordance with one of the aforementioned methods to render the lens subsequently non-adjustable.

It will thus been seen that the apparatus conveniently provides a low-cost
5 solution to the problem of correcting eye defects in a great number of people.

**CLAIMS**

1. An optical apparatus comprising:
at least one liquid lens or flexible membrane mirror;
5 a liquid pump for adjusting the pressure of liquid in the or a cavity
of the lens or mirror;
a closeable duct for interconnecting the said cavity and the pump
permitting the flow of liquid therebetween; and
a closure for closing the duct when the pressure of liquid in the said
10 cavity attains a desired value, whereby to render the lens or mirror
subsequently non-adjustable.
2. An optical apparatus according to Claim 1 wherein the closure
includes a portion of the duct plastically deformable to close the duct.
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3. An apparatus according to Claim 2 wherein the said portion of the
duct is plastically deformable when compressed.
4. An apparatus according to Claim 2 or Claim 3 wherein the said
20 portion of the duct is plastically deformable when heated.
5. An apparatus according to any of Claims 2 to 4 wherein the said
portion of the duct is plastically deformable when subjected to ultrasonic
excitation.
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6. An apparatus according to any preceding claim wherein the pump
is a positive displacement pump capable of increasing and decreasing the
pressure of liquid in the said cavity.
- 30 7. An apparatus according to Claim 6 wherein the pump is a syringe.



8. An apparatus according to any preceding claim, wherein the closure includes a member retentively deformable to close the duct.
9. An apparatus according to Claim 8 wherein:
- 5 (i) the said member includes a resiliently deformable bung closing the duct; and
- (ii) the pump includes or is operatively connected to a further duct capable of removably piercing the bung to permit the flow of liquid between the pump and the said cavity, the resilience of the bung (a)
- 10 creating a liquid-tight seal about the further duct when the further duct pierces the bung, and (b) causing closure of the aperture pierced by the further duct on removal thereof from the bung.
10. An apparatus according to Claim 10 wherein the further duct is a
- 15 hollow needle.
11. An apparatus according to Claim 8 wherein the retentively deformable member includes opposed, interior walls of the duct capable of sealingly adhering one to another on compression of the duct.
- 20 12. An apparatus according to Claim 11 including adhesive matter secured on the opposed, inner walls of the duct.
13. A pair of spectacles including apparatus according to any preceding
- 25 claim, the apparatus including a pair of liquid lenses.
14. A pair of spectacles according to Claim 13 including a respective liquid pump and a respective closeable duct for each lens.
- 30 15. A pair of spectacles according to Claim 13 or Claim 14 wherein the



or each closeable duct is flexible and the frame of the spectacles includes one or more recesses for receiving the or a duct after closing thereof.

16. A pair of spectacles according to Claim 15 wherein the or each
5 recess is closeable to conceal the closed ducts.

17. A pair of spectacles according to any of Claims 13 to 16, wherein each lens includes a rigid, transparent cover for protecting a flexible membrane of the lens.

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18. A pair of spectacles according to Claim 17 wherein the or each transparent cover has an optically corrective effect.

19. A pair of spectacles according to Claim 17 or Claim 18, wherein
15 the or each transparent cover has an optical filtering effect.

20. A pair of spectacles according to any of Claims 13 to 19, wherein the optical apparatus includes one or more compound, fluid lenses.

20 21. An optical apparatus according to any of Claims 1 to 12, or a pair of spectacles according to any of Claims 13 to 20, wherein the or a fluid lens thereof contains a predetermined quantity of liquid, the pump therefor being capable of adjusting the fluid pressure in the lens cavity in a limited range.

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22. A method of adjusting an apparatus for correcting defective eyesight, comprising the steps of:

(i) placing an apparatus according to any of Claims 1 to 12 in front of a patient's eye such that the eye receives light through the or a
30 lens thereof;



(ii) operating the pump of the apparatus until the patient sees an optimum clarity image;

(iii) closing the duct of the apparatus; and

(iv) detaching the pump from the apparatus.

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23. A method of adjusting a pair of spectacles correcting defective eyesight, comprising the steps of, in any practical order:

(i) placing a pair of spectacles according to any of Claims 13 to 21 in front of a patient's eyes so that each of the patient's eyes receives
10 light via a respective lens of the spectacles;

(ii) obscuring the pupil of a first of the patient's eyes;

(iii) operating the pump of the lens associated with the second of the patient's eyes until the said second eye sees an optimum clarity image;

(iv) closing the duct between the said lens and its associated
15 pump;

(v) uncovering the pupil of the first eye;

(vi) obscuring the pupil of the patient's second eye;

(vii) repeating steps (iii) and (iv), *mutatis mutandis*, with respect to the patient's second eye; and

20 (viii) detaching the or each pump from the apparatus.

24. A method according to Claim 23 wherein the spectacles accord to Claim 15, comprising the further steps of:

(ix) after closing, placing each duct in a recess of the spectacles;

25 and

(x) covering the or each recess.