Oct. 9, 1962 MASAHIKO KIMURA ETAL 3,057,351

INTRAVENOUS INJECTION SYRINGE

Filed Oct. 27, 1960

FIG. 1.

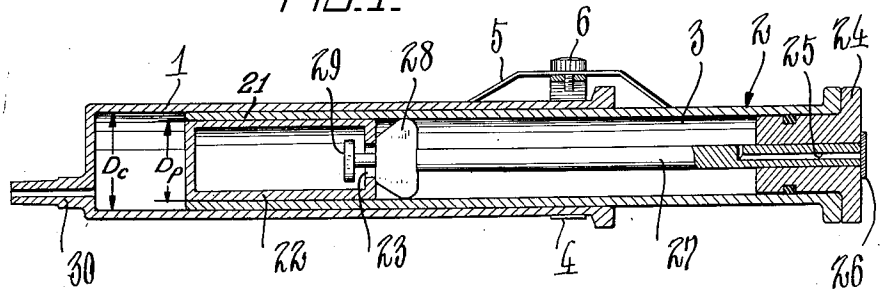


FIG. 2.

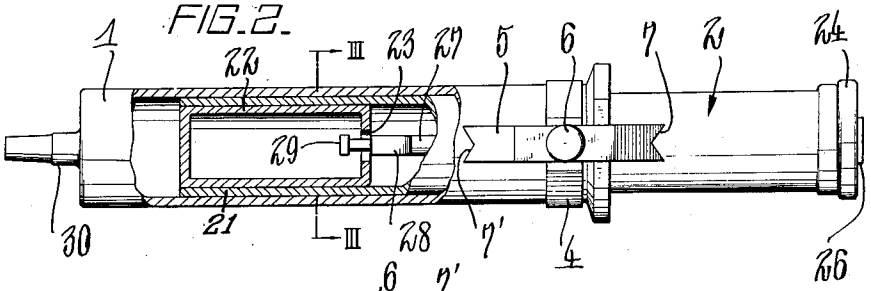


FIG. 3.

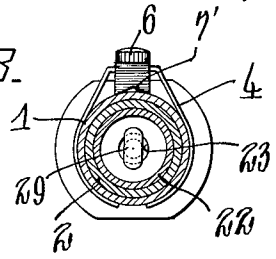
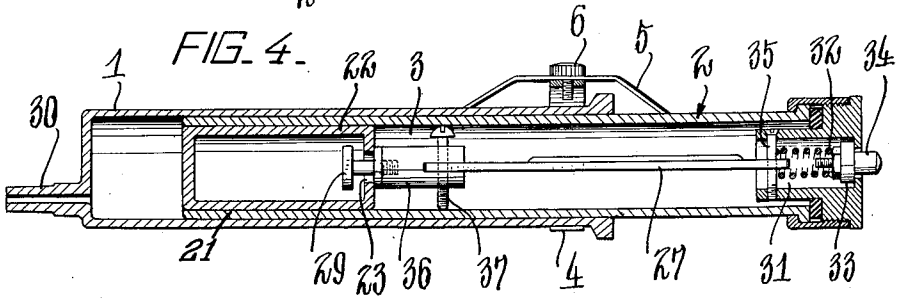


FIG. 4.



United States Patent Office 3,057,351 Patented Oct. 9, 1962

3,057,351

INTRAVENOUS INJECTION SYRINGE

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Filed Oct. 27, 1960, Ser. No. 65,329
Claims priority, application Japan Nov. 16, 1959
8 Claims. (Cl. 128—218)

This invention relates to intravenous injection syringes.

In injecting medicine intravenously, the needle of the injection syringe is inserted under the skin, the vein is probed and then injected after confirming that the tip of the needle is inside the vein. With conventional syringes there was no indication of whether the tip of the injection needle was properly positioned in a vein other than to pull out the plunger of the injection syringe slightly to reduce the pressure in the barrel until blood flowed into the barrel. Accordingly, it became necessary to repeat this operation several times which required a longer time for the injection and caused considerable pain to the patient. Furthermore, this operation required the development of special skill.

It is an object of this invention to provide an intravenous injection syringe in which it is very simple to determine that the tip of the injection needle has been inserted in the required location in the vein.

Another object of this invention is to provide an intravenous injection syringe in which blood will flow automatically into the barrel when the tip of the injection needle is inserted into the vein, by which, it can be easily recognized that the needle is in the required location.

Previously, we have proposed an intravenous injection syringe in which the plunger is made of double cylinders and said inner top closed free cylinder was fitted movably in the operating cylinder which has its open end and fitted movably in the barrel. In this injection syringe, an air-tight cavity is formed in the plunger, its volume is determined by the relation between the operating cylinder and the free cylinder and the pressure in the air-tight cavity is in inverse proportion to its volume. Consequently, this pressure will become lower when the volume of this air-tight cavity increases and this pressure can be determined from the relative positions of the operating cylinder and the free cylinder.

When medicine is drawn into this intravenous injection syringe and the plunger pulled out slightly after inserting the needle point under the skin, the air-tight cavity in the plunger becomes a negative pressure and as a minus pressure equal to this negative pressure acts on the needle with the medicine as medium, venous blood is automatically drawn into the injection syringe when its tip enters the vein, by which it can be recognized that the needle has entered the vein. Thus, by this intravenous injection syringe, it can be recognized that the needle has been inserted into the vein even when the blood pressure in the vein is low.

However, as the plunger of this injection syringe is only composed of an operating cylinder and a free cylinder which are both slidable to each other and as the relative position of both cylinders are not limited, the negative pressure within the air-tight cavity increases without limit when the operating cylinder is drawn outward, resulting in the clogging of the needle with a part of the subcutaneous tissue which is destroyed and sucked in. It is therefore necessary for the user to take special care in using this. Also, the friction between the free cylinder and the operating cylinder is large in this injection syringe as the free cylinder is considerably large,

by which, it was discovered that blood will not flow into the injection syringe as the free cylinder does not return with some injection medicine even when the needle reaches inside the vein. Also, this injection syringe is not practical as there were difficulties in fixing the position of the plunger and in maintaining the negative pressure in the air-tight cavity constant.

This invention is an improvement of the injection syringe described above and with the above-mentioned defects removed.

The intravenous injection syringe of this invention is composed of a barrel and a plunger consisting of an outer cylinder having an end plug and an inner cylinder having a bottom which can slide freely and inserted such that its open end is positioned inward, and said inner cylinder is hooked a fixed movable distance by hook on the end of the support rod which is an extension from the plug and a restraining device is provided on the outside tip of the barrel to press the plunger.

By this invention the intravenous injection syringe is so improved that a free cylinder restraining rod is provided in order to make the maximum withdrawing distance constant thereby to prevent the negative pressure in the barrel from becoming excessively large.

Secondly, it is so improved that the length of the free cylinder is made as short as possible within the range that it does not obstruct the maintenance of air-tightness and that the free cylinder moves freely even with a small change in pressure.

Thirdly, it is so improved tha the position of the plunger is fixed by pressing on the plunger with an elastic plate piece or other pressure applying device attached near the flange on the outside of the barrel to prevent the movement of the plunger while the vein is being probed and thus prevent the change in pressure in the barrel. That is, frictional resistance between the plunger and barrel is increased when the side of the plunger is pressed by the elastic plate piece and also the axes of both cylinders become inclined thereby to increase the contact pressure between the two and to fix the position of the plunger securely.

This invention will become more clear by the following description with reference to the accompanying drawings.

FIG. 1 is a longitudinal side view showing one embodiment of the intravenous injection syringe according to the invention.

FIG. 2 is a plan view with a part cut away.

FIG. 3 is a view taken on line III—III of FIG. 2, and

FIG. 4 is a longitudinal side view of another embodiment of this invention.

In FIGS. 1–3, **1** shows a barrel, and **2** a plunger comprising an operating cylinder **21** and a free cylinder **22**, said plunger being inserted air-tight and slidably into the barrel.

Free cylinder **22** is fitted air-tight and slidably in the operating cylinder **21** and has a small round hole **23** at the inner end. The outer end of the operating cylinder is sealed with a plug **24** thereby forming an air-tight chamber **3** in the operating cylinder **21** and the free cylinder **22**. A rod **27** supporting the free cylinder is extended through the plug **24** and has a hooking head **29** having a lateral width which is smaller than the diameter of the round hole **23** of the free cylinder and a longitudinal width which is larger than the diameter of said round hole whereby the hooking head **29** can be inserted in the hole of the free cylinder. The outer end of the support rod is provided with a hollow **25** which connects the cavity **3** to the atmosphere. Numeral **26** designates a cover such as adhesive tape which plugs the hollow. To this support rod is attached a wing piece **28**

having a width approximately the same as the inside diameter of operating cylinder **21** and positioned at a fixed distance from the hooking head **29**. The wing piece **28** is positioned on the rod such that the outer end of the free cylinder is coplanar with the end of the operating cylinder **21** when wing piece **28** is in contact with inner end of the free cylinder **22**.

Since hooking head **29** has a rectangular shape, it will pass through the round hole **23** when the axes of the support rod is inclined with respect to the free cylinder **22** and will hook on the rim of the round hole when the axes of the free cylinder and the support rod coincide.

Consequently, in the condition shown in FIG. 1 and FIG. 2, the pressure of the medicine cavity of the barrel **1** will be reduced if the plunger is pulled back with the closed nozzle **30** of the barrel for attaching the injection needle and the free cylinder **22** will protrude from the end of the operating cylinder **21** only to a distance equivalent to that between hooking head **29** and wing piece **28**. Also, when the pressure in the medicine cavity becomes high, the free cylinder **22** will be drawn into the operating cylinder to a distance in which its inner end contacts the wing piece.

A clip **4** is provided on the outside end of the barrel and an elastic plate piece **5** is rotatably attached to this clip by means of a pivot **6**. The elastic plate piece has cuts at both ends **7**, **7'** and when it is positioned in the axial direction of the barrel, one end **7'** touches the outside surface of the barrel and the other end **7** touches the outside surface of the operating cylinder. As the piece member **5** is bent so as to press the cylinder **21** with a slight pressure, the operating cylinder **21** is maintained in a fixed position when the elastic plate piece is in this position.

Now, the use of this injection syringe will be explained in the order of disassembly, assembly, insertion and injection. First, after turning the elastic plate piece **5** in a position perpendicular to the axis line of the injection syringe, the plunger **2** can be pulled out from the barrel **1**. Next, in order to disassemble the plunger, an adhesive tape **26** closing an air hole **25** is removed and plug **24** is removed from the operating cylinder, by which the support rod and the free cylinder can be withdrawn from the operating cylinder together with the end plug.

If it is desired to dismantle the free cylinder further, the hooking head **29** can be slipped out through the round hole **23** when the support rod is inclined with respect to the free cylinder and then the support rod can be removed from the free cylinder. The injection syringe can be sterilized when in this dismantled condition.

In assembling the injection syringe, the plug **24** is picked up with the fingers, the support rod and free cylinder which is connected to it is inserted into the operating cylinder, and the plug **24** is plugged into the operating cylinder to assemble plunger **2** which is then inserted into the barrel **1**. The elastic plate piece **5** is turned such that it coincides with the axial direction of the injection syringe to lock plunger **2** and barrel **1** together. While assembling, the air hole in the plug remains unsealed.

Next, the heads of free cylinder **22** and operating cylinder **21** are aligned in the same plane and then the air hole **25** is closed with a cover **26** such as adhesive tape. Thereafter a needle is attached to nozzle **30** and the plunger is pulled out to fill the cavity between the barrel and the plunger with medicine, whereby preparation for injection is completed.

In inserting the injection syringe, first the needle tip is inserted below the skin, the plunger is pulled out slightly from the barrel **1** in this condition and this pulling-out is stopped when the movement of the plunger stops. In this condition, the medicine cavity is in a reduced-pressure condition as the tip of the needle is sealably closed by muscles and the free cylinder will protrude beyond cylinder **21** and up to the position of the hooking head. At this time, without exposing the needle tip outside of the skin by removing the hand from the plunger and grasping the barrel, the vein is searched. When the needle tip reaches the vein, venous blood will be drawn automatically into the medicine cavity regardless of how low the blood pressure is in the vein, which indicates that the needle tip has intercepted the vein. After this, the plunger can be pressed in this position in a similar manner as that of conventional method, to carry out injection.

The injection syringe shown in FIG. 4 is the same in principle as that shown in FIG. 1 to FIG. 3 but shows improvements in the plug, support rod and seal of air hole.

A spring **32** is housed in the cavity **31** of the plug of the plunger, this cavity **31** is normally sealed by a valve **33** by its elasticity and the inside of the cavity can be made to connect with the atmosphere by pressing the protruding part **34** of the valve **33** inward.

Also, in this embodiment, the support rod **27** is fixed inside the cavity of the plug by a screw **35**, an enlarged part **36** and hooking head part **29** having a fixed distance therefrom are provided on the tip of the support rod and also a screw **37** is provided to maintain the support rod concentric with the operating cylinder.

In this injection syringe, the balance between the pressure of sealed cavity of the plunger and the atmosphere can be easily maintained by merely pressing the protruding part **34** of the valve. The other operations are exactly the same as mentioned above.

Besides intravenous injection, the injection syringe of this invention can be used as an auxiliary device for blood transfusion by using a blood transfusion bottle. The middle part of blood transfusion tube on which preparation has been made for transfusion is closed with a clamp or coffer, glucose or physiological solution of sodium chloride is filled in the injection syringe of this invention and its needle is inserted in the above-mentioned blood transfusion tube. When the plunger **2** is pressed into the barrel **1**, just as in the case of injection, to an appropriate extent, blood for transfusion in the blood transfusion needle and observation tube will be extruded through the hollow of blood transfusion needle and replaced by the above-mentioned transparent solution. Then, when the blod transfusion needle is inserted under the skin to search for the blood vessel, and the operating cylinder **21** is pulled out until it stops automatically, negative pressure will be produced in the observation tube and the connecting part, and when the vein is found, venous blood will be seen in the observation tube of the above-mentioned blood transfusion needle. Then, when said clamp or coffer is removed to open the blood transfusion tube, blood transfusion will begin. However, as the negative pressure in this intravenous injection syringe is made very small, the level of the clamp or coffer must be made almost the same as the level of the part in which the blood transfusion needle is to be inserted in the patient. Also, when a blood transfusion tube in which there is danger of leakage, such as when a vinyl tube is used, the injection needle is not inserted directly in the blood transfusion tube as in the case of rubber tube, and instead the part in which the needle of the injection syringe is to be attached is preferably connected to a side tube by way of a Y-tube inserted in an appropriate portion of the blood transfusion tube.

The mechanical function of the intravenous injection syringe of this invention is explained theoretically below. However, this invention is not limited by this theory.

Dc in FIG. 1 indicates the inner diameter of the barrel **1**, which is the same as the outer diameter of the operating cylinder **21**. Dp is the outer diameter of the free cylinder **22**, which is equal to the inner diameter of the operating cylinder. Also, in the plunger **21**, the rear end of the free cylinder **22** contacts the front rim of the wing **28** of the free cylinder controlling rod **27** as shown in FIG. 2, the volume of the plunger cavity **3** being a

minimum when the end without the hole is aligned with the operating cylinder **21**, and this minimum value of plunger cavity is designated as V (cm.^{3}). Here, it is assumed that the condition is such that medicine is filled in the injection syringe, air bubble removal is completed, and that the needle point is inserted under the skin and the needle cavity is closed. In such a case, when only the barrel **1** is held and the plunger **2** left free, the plunger **2** will receive force from the atmosphere P*a* (kg./cm.^{2}) such that it is pushed into the barrel **1** and the plunger will stop as it only presses on the liquid as the medicine in the medicine cavity is non-compressible. If K*a* (kg.) is taken as the force of the atmosphere pressing on the plunger **2**, it will be

$$Ka=Pa\cdot\frac{\pi Dc^2}{4} \tag{1}$$

wherein the pressure of the medicine is P*a* and the air pressure in the plunger cavity is also P*a* as it was left at the atmospheric pressure when it was assembled.

The free cylinder **22** will not move also as the forces are balanced. The operating cylinder **21** can be pulled out with a relatively small force by hand. At this time, if X is taken as the length to which the operating cylinder **21** can be pulled out from the barrel **1** and if the free cylinder also moves together with the operating cylinder **21**, the volume of the medicine cavity increases by

$$\frac{\pi}{4}Dc^2$$

by this movement. However, as the volume of the medicine is unchangeable and as the free cylinder protrudes in the medicine cavity side in order not to form a vacuum space, the above volume of the medicine cavity is maintained unchanged. When the distance (that is, the distance which it protrudes in the medicine cavity) in which the free cylinder **22** is pulled out from the operating cylinder **21** is designated as *y*, the volume of the part which protrudes becomes

$$\frac{\pi}{4}Dp^2\cdot y$$

As this quantity is equal to the above-mentioned

$$\frac{\pi}{4}Dc^2\cdot x$$

the relation between X and *y* can be represented by the following equation:

$$\frac{x}{y}=\frac{Dp^2}{Dc^2} \tag{2}$$

However, as this equation is true when the free cylinder is in such a condition that it is within the limit of being freely movable, it will not be applicable in a condition where the movement of the free cylinder is prevented by the button head **29**.

From the Equation 2, it can be seen that X is proportional to *y* and the proportion constant is the square of the proportion of the outer diameter of the free cylinder and the inside diameter of the barrel **1**. Therefore, if the free cylinder **22** protrudes by *y* only, the volume of the plunger cavity **3** is formed by the two increases. It is apparent that the quantity of increase is

$$\left(\frac{\pi}{4}Dp^2\cdot y\right)\text{cm.}^3$$

Consequently, the volume of the plunger cavity **3** at such a time will be

$$V+\frac{\pi}{4}Dp^2\cdot y \tag{3}$$

At first, as the volume of the plunger cavity **3** was V at atmospheric pressure P*a*, but now the volume changes to

$$V+\frac{\pi}{4}Dp^2\cdot y$$

so then the pressure P*u* (kg./cm.^{2}) of the plunger cavity **3** after the change in its volume will be as follows, according to Boyle's law, if it is assumed that there is no temperature change during this time.

$$Pa\cdot V=Pu\left(V+\frac{\pi}{4}Dp^2\cdot y\right) \tag{4}$$

In this equation

$$Pa>Pu \text{ as } V<V+\frac{\pi}{4}Dp^2$$

In this case, it is recognized that pressure P*u* of plunger cavity **3** is lower than the atmospheric pressure, in other words, there is a negative pressure in the plunger cavity **3**. Equation **4** can be rewritten in another form,

$$y=\frac{Pa-Pu}{\frac{Pu}{\frac{\pi Dp^2}{4}\cdot V}} \tag{4'}$$

(*Pa—Pu*) in this equation is the difference between atmospheric pressure P*a* and plunger cavity pressure P*u* and shows the quantity of negative pressure. A negative pressure of about 0.01–0.05 kg./cm.^{2} is considered to be appropriate as negative pressure in order to suck in blood from the vein and consequently, a value within the range of 0.01–0.03 kg./cm.^{2} is taken as the value of negative pressure (*Pa—Pu*). Here, the value of P*u* can be obtained by subtracting P*a* from (*Pa—Pu*) as P*a* can be measured with a barometer.

V and D*p*^{2} is fixed from the equipment. Consequently, the Equation 4′ is an equation showing the value of *y* for obtaining the required negative pressure (*Pa—Pu*). At the same time, the value X is the distance wherein the operating cylinder **21** should be pulled out in order to obtain the required negative pressure. Now, if the operating cylinder **21** is pulled out to this distance and stopped, and then maintained at this distance, the free cylinder **22**, which is freely movable, will move to an equilibrium position and then stay still there due to the balance in pressure on both sides. One side of them is the plunger cavity **3** and its pressure is P*u*. Also, as the forces which try to draw out the plunger **2** from barrel **1** are the force

$$\frac{\pi}{4}Dc^2\cdot Pu$$

by the pressure of the medicine and for K(kg.) of the user who tries to pull out the plunger **2** and as the force which tries to push in the plunger **2** into barrel **1** is K*a*(kg.) by the atmospheric pressure as shown in Equation 1, these forces balance and become

$$\frac{\pi}{4}Dc^2\cdot Pu+K=\frac{\pi}{4}Dc^2\cdot Pa$$

and when this is rearranged, it will become

$$K=\frac{\pi}{4}Dc^2(Pa-Pu) \tag{5}$$

From this equation, the value of force *k* for pulling out plunger **2** can be obtained, which is necessary to give negative pressure (*Pa—Pu*) to the space in the plunger cavity and also to medicine.

The following equation can be obtained from Equations 4′ and 5.

$$K=\frac{\frac{\pi}{4}Dc^2\cdot\frac{\pi}{4}Dp^2\cdot Pu}{V}\cdot y \tag{6}$$

In this equation, D*c*, D*p* and V are fixed by the equipment and as P*u* is fixed by the value of negative pressure (*Pa—Pu*), it can be seen that K and *y* are proportional. However, this force K can apply negative pressure (*Pa—Pu*) to the medicine even with the ordinary conventional injection syringe by pulling out plunger **2** but

actually, it is difficult to pull with a force of K accurately as it is done by hand manipulation of poor accuracy and also, it is almost impossible to maintain this force K constant without special equipment. However, if a plunger with free cylinder is used as in this invention, the strength of force for pulling out the plunger can be measured with the eye as K is proportional to the protruding amount of free cylinder *y* and also the amount of movement of operating cylinder X, by using either as a standard. Consequently, the force of hand can be controlled so that it equals the required force. Furthermore, according to this invention, the value of *y* is controlled as the back end of the button head **29** touches the bottom wall of the plate of the free cylinder **22** with the round hole **23** and the free cylinder will not protrude further than this when the plunger **2** is pulled out and free cylinder **22** protrudes. If the distance of free cylinder controlling rod **27** is set such that the optimum required negative pressure is obtained in the limiting value of this *y*, the operator will only have to pull out lightly on the plunger **2** without considering the force with which to pull out plunger **2** or the protruding amount of free cylinder **22** by stopping to pull when the feeling on the hand becomes heavy suddenly, by which *y* will reach its limiting value and the pressure within the barrel will become the required negative pressure. Also, the negative pressure in the barrel is maintained negative pressure as the position of the operating cylinder which is pulled out is automatically maintained by means of the elastic plate piece **5** acting on the operating cylinder **21**. When *y* reaches the limiting value during this operation, the feeling on the hand which is pulling on the operating cylinder becomes heavy and will not move with a light force and if the operating cylinder is tried to be pulled out in spite of this, the resistance will increase rapidly and this will become clear easily to the operator. When this is shown by numerical values when the inside diameter Dc of the barrel is 1.9 cm. and the required negative pressure is 0.03 kg./cm.^{2}, the force K necessary to pull out operating cylinder **21** will become

$$\frac{\pi}{4}1.9^2\cdot 0.03=0.085 \text{ (kg.)}$$

from the Equation 5. This force will increase severely if the operator tries to pull out the operating cylinder **21** furthermore, notwithstanding the hooking head **29** acts and stops the protrusion of free cylinder **22**. So powerfully pulled, the operating cylinder **21** together with cylinder **22** begins to slide out of the barrel **1** while producing absolute vacuum in the medicine cavity. In this condition P*u* becomes 0. Now we put $Pu=0$ into the Equation 5 and get

$$Kpu=0=\frac{\pi}{4}Dc^2Pa$$

Comparing this equation with the Equation 1, we know that K and K*a* become equal and calculated by substituting numerical values in Equation 1

$$Ka=2.834 \text{ (kg.)}=K$$

Therefore, it can be understood from the above two values, 0.085 kg. and 2.834 kg., that there is a great difference and that there is no chance for neglect to notice to become involved. However, atmospheric pressure is an important standard for calculation in this equipment as can be seen from the fact that negative pressure is represented as $(Pa-Pu)$ and depending on the weather, the atmospheric pressure is not necessarily constant. The standard pressure is 1.033 kg./cm.^{2} when weather records are collected and there are examples of a maximum high pressure of 1.046 kg./cm.^{2} and a minimum low pressure of 0.954 kg./cm.^{2}. Consequently, as doubt will arise as to whether there is considerable difference in the required pressure of the negative pressure due to the effect of high and low atmospheric pressures in a construction such as that of this invention where the amount of *y* is constant, a discussion on this will be given. When Equation 4 is changed to another form and a fixed limiting value is given for *y*, the following equation will be obtained:

$$\frac{Pa}{Pu}=\frac{V+\frac{\pi}{4}Dp^2\cdot ys}{V}$$

When the injection syringe of this invention is used, the right side of this equation is constant. This constant is designated as C. If the atmospheric pressure which differs from the standard value is P*a*^{1}, the pressure in the plunger cavity **3** is P*a*^{1} from the beginning as atmospheric pressure is in it when it was assembled. When operating cylinder **21** is pulled out in this condition and free cylinder **22** protrudes the fixed distance *ys*, and if the pressure in the plunger is assumed to have dropped to P*u*^{1}, the following relation will be obtained from the pressures before and after:

$$\frac{Pa^1}{Pu^1}=C$$

therefore,

$$C=\frac{Pa}{Pu}=\frac{Pa^1}{Pu^1}$$

Consequently, the following relation will result,

$$\frac{Pa}{Pa^1}=\frac{Pu}{Pu^1}=\frac{Pa-Pu}{Pa^1-Pu^1} \qquad (7)$$

When there are two atmospheric pressures, P*a* and P*a*^{1}, it is clear that the ratio of $(Pa-Pu)$ and (Pa^1-Pu^1) are equal to the ratio of atmospheric pressures P*a* and P*a*^{1} when the injection syringe is operated in a similar manner. That is, if the standard of atmospheric pressure P*a* is taken as 1.033 kg./cm.^{2} and the length of *ys* is fixed such that the required negative pressure after operation, for example 0.03 kg./cm.^{2}, is fixed, that is, if it is made such that the effect of hooking head **29** stops when the free cylinder **22** protrudes *ys* distance, when designing this injection syringe, by the ratio of negative pressure produced when operated at the maximum recorded pressure of $Pa^1=1.046$ kg./cm.^{2}, the calculation will be,

$$Pa^1=Pu^1=0.03\cdot\frac{1.046}{1.033}=0.030375 \text{ (kg./cm.}^2\text{)}$$

Also, by the ratio of negative pressure produced when operated at the minimum recorded pressure of $Pa^2=0.954$ kg./cm.^{2}, the calculation will be

$$Pa^2-Pu^2=0.03\cdot\frac{0.954}{1.033}=0.027705 \text{ (kg. cm.}^2\text{)}$$

As the error in negative pressure resulting from the two extreme cases is +1.2% and −7.65%, respectively, it can be seen that is not necessary to be concerned about this in actual use as these values are within the appropriate range for use. Next, the case where error in *y* occurs will be discussed. The value of *y* cannot become larger than the required value as it is constructed such that the protruding amount *y* in the injection syringe of this invention is controlled by the hooking head **29** and it cannot protrude further than this and as vein is searched while it is maintained at the maximum quantity of *ys* but there is a possibility of this value to become less than the limiting value by mistake. The quantity of the required value affected by this error is next discussed. If *i* is taken for $(Pa-Pu)$, $Pu=Pa-i$. When these symbol relations are substituted in Equation 4′ it will take the form of

$$y=\frac{V}{\frac{\pi}{4}Dp^2}\cdot\frac{i}{(Pa-i)} \qquad (4'')$$

If *i* variation is produced in *i* by Δy variation in *y*, Equation 4″ will become

$$y+\Delta y=\frac{V}{\frac{\pi}{4}Dp^2}\cdot\frac{(i+\Delta i)}{Pa-(i+\Delta i)} \qquad (\Delta 4)$$

If both sides of this equation is divided by both sides of Equation 4'' and then 1 is subtracted from both sides, the following equation is obtained,

$$\frac{\Delta y}{y}=\frac{\Delta i}{i}\cdot\frac{Pa}{(Pa-i)-\Delta i} \qquad (\Delta 4')$$

If numerical values of $y=0.35$ cm., $i=0.03$ kg./cm.^{2}, $Pa=1.033$ kg./cm.^{2} are taken, and consequently, an error of $y=0.1$ cm. results when $Pa-i=1.003$ kg./cm.^{2}, the result of calculation of i when the various values are substituted in Equation 4' will be

$$\Delta i=0.00825 \text{ kg./cm.}^2$$

It can be seen that the required negative pressure of 0.03 kg./cm.^{2} will be reduced by 0.00825 kg./cm.^{2} to become 0.02175 kg./cm.^{2} when the standard value of $y=0.35$ cm. is reduced by 0.1 cm. to become 0.25 cm. The error is 27.5% and is not small percentagewise but as the appropriate range of negative pressure value in use is considered to be 0.1—0.05 kg./cm.^{2} as mentioned above, it can be seen that no difficulty will be encountered in actual use even when considerable difference results in the operation of this injection syringe.

In the above deliberation, it was assumed that isothermal expansion of air in the plunger cavity will occur when the free cylinder **22** protrudes and the volume of this cavity increases. The reason for this is that it can be considered that the temperature remains unchanged as the cooling due to expansion is compensated by heat from the hand holding the injection syringe and from the air in the room. Also, another reason is that the equation and calculation will be more simple and easy when isothermal change is assumed. However, it is probably better to consider this air expansion as adiabatic expansion as it can be considered that there is no time for exchange of heat as the time required for the operation of pulling out the plunger is relatively short and also, as glass has some heat insulation property. In this case, the relation between pressure P and volume V generally follows the following equation

$$PvK=C$$

C is a constant and K is the ratio of specific heats and is 1.4 for air. In this injection syringe, the pressure in the plunger cavity **3** is Pa (kg./cm.^{2}) and volume is V (cm.^{3}.) at first, pressure change to Pu (kg./cm.^{2}) and volume to

$$V+\frac{\pi}{4}Dp^2\cdot ys(\text{cm.}^3)$$

when the plunger **2** is pulled out and the free cylinder protrudes ys (cm.). Consequently, the following equation is substantiated

$$Pa\cdot V^k=Pud\left(V+\frac{\pi}{4}Dp^2\cdot ys\right)^k \qquad (8)$$

In this equation, Pud was used especially to show that the pressure of plunger cavity, Pu, is due to adiabatic change atfer the change occurred. In contrast to this, in the case of isothermal change,

$$PaV=Put\left(V+\frac{\pi}{4}Dp^2\cdot ys\right) \qquad (4t)$$

is obtained from Equation 4. In this, Put was used especially to show that pressure of plunger cavity Pu is due to isothermal change after the change occurred. When the same injection syringe is used under the same atmospheric presure, Pa, V, Dp^2 and ys will each be the same in Equations 8 and 4t. Now, when both sides of Equation 4t is raised to the K power and divided by both sides of Equation 8,

$$\frac{Pa^k}{Pa}=\frac{Pu^k}{Pud}$$

$$\therefore\frac{Pud}{Pa}=\left(\frac{Put}{Pa}\right)^k \qquad (9)$$

In this equation, as

$$0<\frac{Pud}{Pa}<1 \qquad 0<\frac{Put}{Pa}<1 \qquad K=1.4$$

$$\frac{Pud}{Pa}<\frac{Put}{Pa} \qquad \therefore Pud<Put$$

From this, it can be seen that the pressure in the cavity due to adiabatic change is lower than that obtained by isothermal change. Consequently, negative pressure due to adiabatic change is larger. Now, when numerical values are used as an example and negative pressure produced when adiabatic change actually takes place is calculated when the injection syringe of this invention is designed and manufactured for operation under atmospheric pressure to obtain the required negative pressure, 0.03 kg./cm.^{2}, the plunger cavity pressure will be

$$Put=1.003 \text{ kg./cm}^2.$$

by isothermal change.

When numerical values are substituted in Equation 9, it will be

$$\frac{Pud}{1.033}=\left(\frac{1.003}{1.033}\right)^{1.4}$$

$Pud=0.9912$ kg./cm.^{2}

Therefore, the negative pressure will be

$$1.033-0.9912=0.0418 \text{ kg./cm.}^2$$

The error of this value is 0.0118 kg./cm.^{2} from the required value of 0.03 kg./cm.^{2} and in percentage, it is 39.3%. This value is not low percentagewise but is in the usable range as negative pressure. Furthermore, as the value of y is controlled such that it does not become larger than a fixed value ys by the hooking head **29** in this invention, the value of negative pressure is controlled such that it does not become excessive even in the case of adiabatic change. As it is considered that the actual change which occurs in the plunger cavity **3** is polytropic change which is intermediate of isothermal change and adiabatic change, the required negative pressure or a value very close to it can be always obtained if the injection syringe is manufactured by obtaining mean polytropic index by numerous experiments and fixing the various values Dp, V, y, etc., accordingly.

This intravenous injection syringe is ideal for general intravenous injection and its effect is especially conspicuous when used on patients with low blood pressure as the various automatic controlling mechanisms of the intravenous injection syringe of this invention which are useful in negative pressure insertion, operates accurately as mentioned above. Furthermore, it is very practical as it is easy to handle.

What we claim is:

1. An intravenous injection syringe comprising a hollow barrel having a closed end adapted for connection with a needle for utilization of said syringe, a plunger slidably supported in said barrel in airtight sealing relation, said plunger including inner and outer elements in sliding relation with one another, said outer element having an open end facing said closed end of the barrel and said inner element having a closed end facing said closed end of the barrel to form a reservoir between said barrel and plunger, and means coupled to said inner and outer elements and permitting relative movement therebetween between limit positions corresponding to conditions of high and low pressure in said reservoir whereby a first relative position is assumed between said inner and outer elements with said syringe positioned for penetration into a vein, the latter said elements moving relative to one another to assume the other of said relative positions under the action of the pressure of blood in said reservoir with the needle of the syringe penetrating a vein.

2. A syringe as claimed in claim 1, wherein said means comprises a plug in said outer cylinder at an end remote from said open end to close the same, said inner element having an opening providing communication between the

interiors of the inner and outer elements to define a chamber, a rod supported in said plug and extending through the opening of the inner element and into the interior thereof, a hooking head on said rod in said inner element and of larger size than said opening to define one of said limit positions with said hooking head abutting said inner element and a further element on said rod spaced from said hooking head and in the interior of said outer element, said further element being of larger size than the opening in the inner element to define the other of said limit positions, with the further element abutting said inner element.

3. A syringe as claimed in claim 2, wherein said rod is provided with an opening providing communication between said chamber and the atmosphere, said syringe comprising means operatively associated with said rod for closing communication between the opening therein and the atmosphere.

4. A syringe as claimed in claim 2, wherein said further element is of wing shape for engaging said outer element in sliding relation and maintaining said rod radially of said outer element.

5. A syringe as claimed in claim 4, wherein said plug and wing shaped element position said rod coaxially with respect to said outer element.

6. A syringe as claimed in claim 1, wherein said inner and outer elements are of cylindrical shape and concentrically positioned in said barrel.

7. A syringe as claimed in claim 2, wherein said plug has a cavity providing communication between the atmosphere and the chamber, a valve interrupting communication between the cavity and the atmosphere and spring means coupled to said valve and normally maintaining the same in closed position.

8. A syringe as claimed in claim 7 comprising means on said valve extending externally of said plug and engageable to open the valve against the action of said spring means.

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