April 3, 1945. R. C. BAKER 2,373,006

MEANS FOR OPERATING WELL APPARATUS

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Fig. 1.

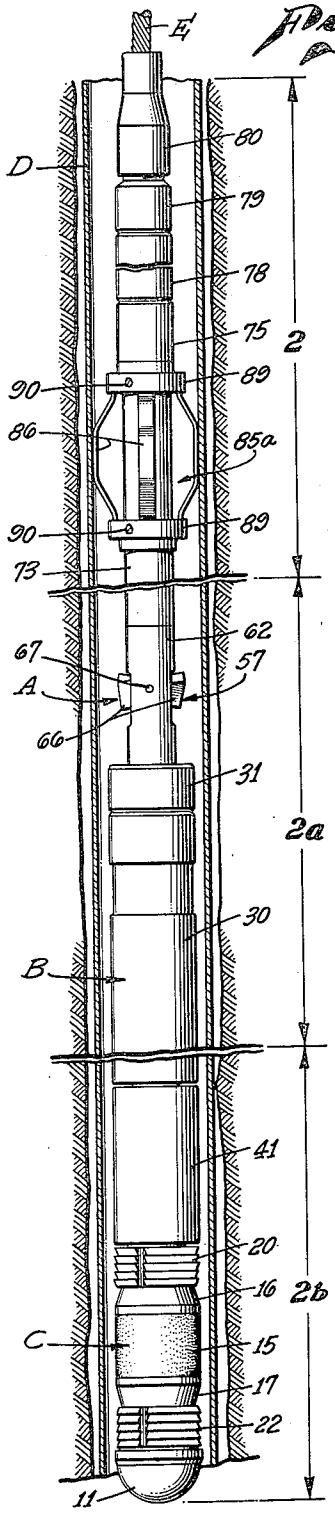

Fig. 2.

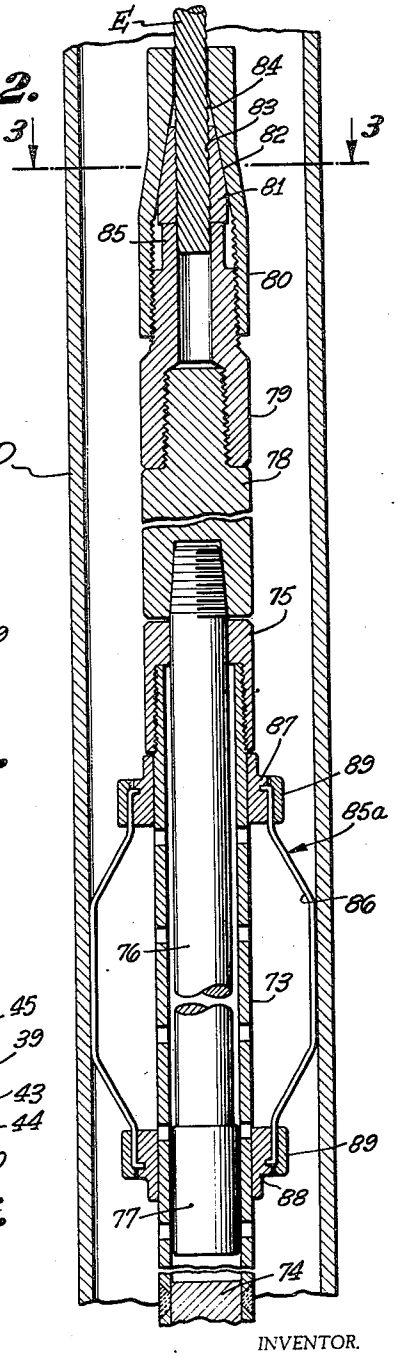

Fig. 3.

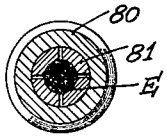

Fig. 4.

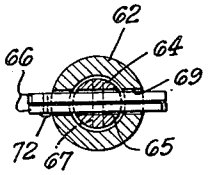

Fig. 5.

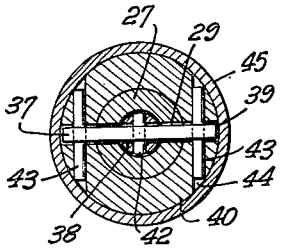

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Fig. 2a.

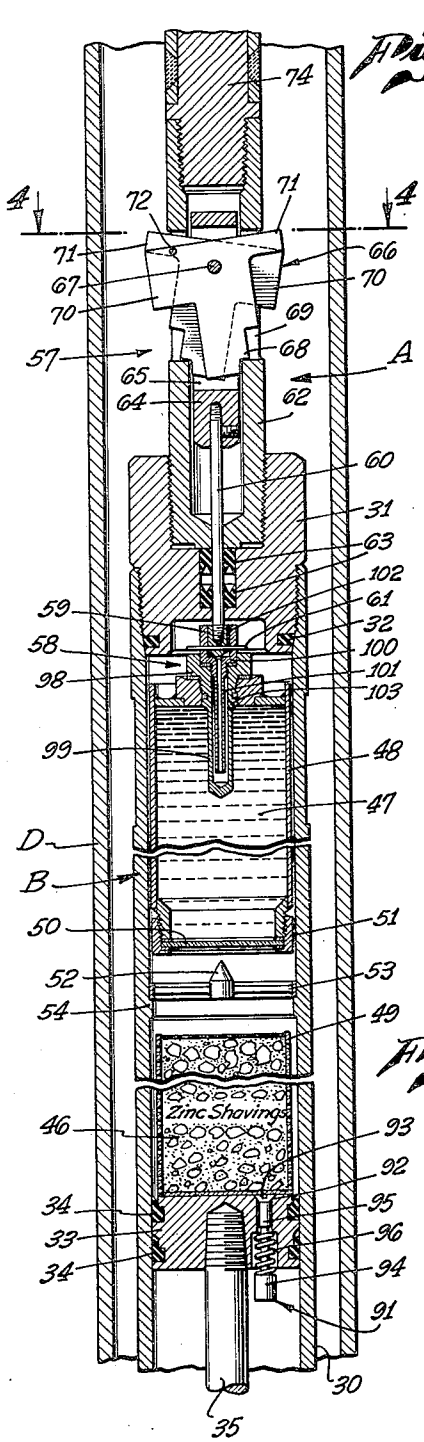
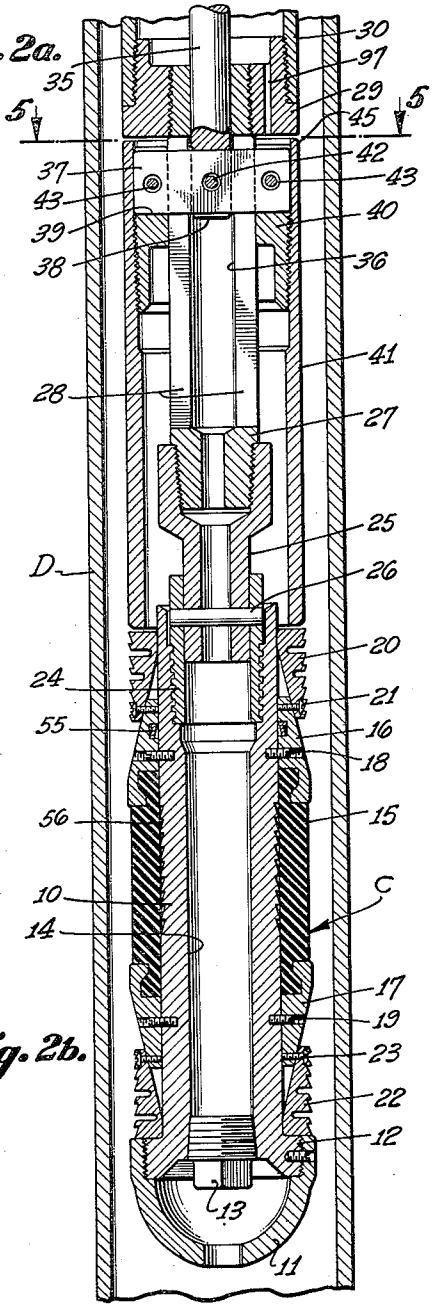


Fig. 2b.



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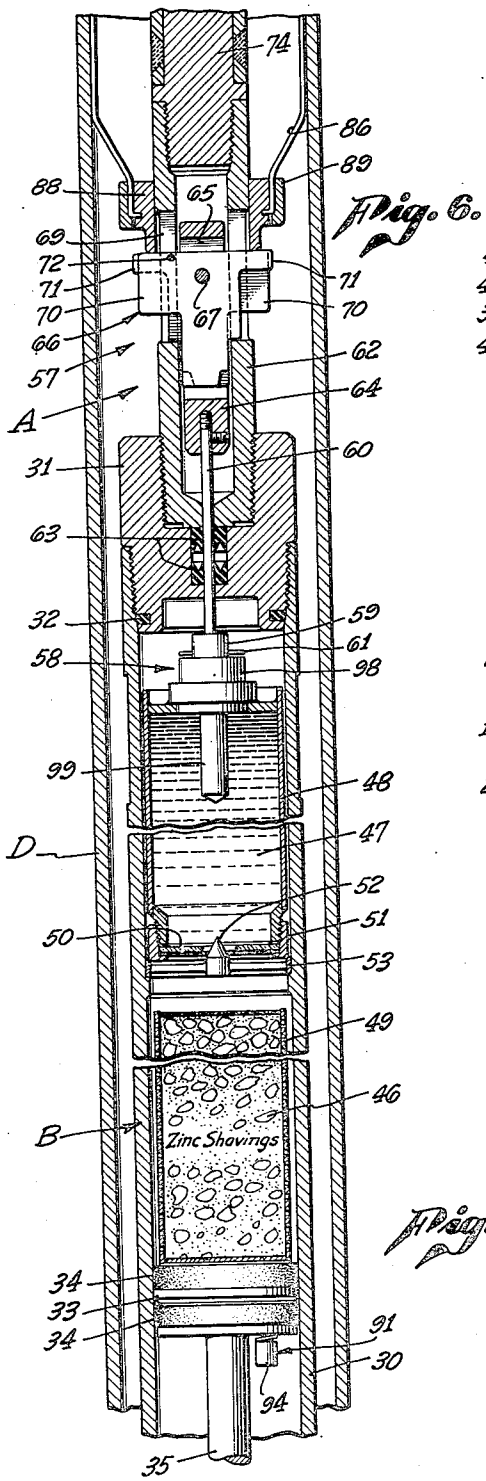

Fig. 6.

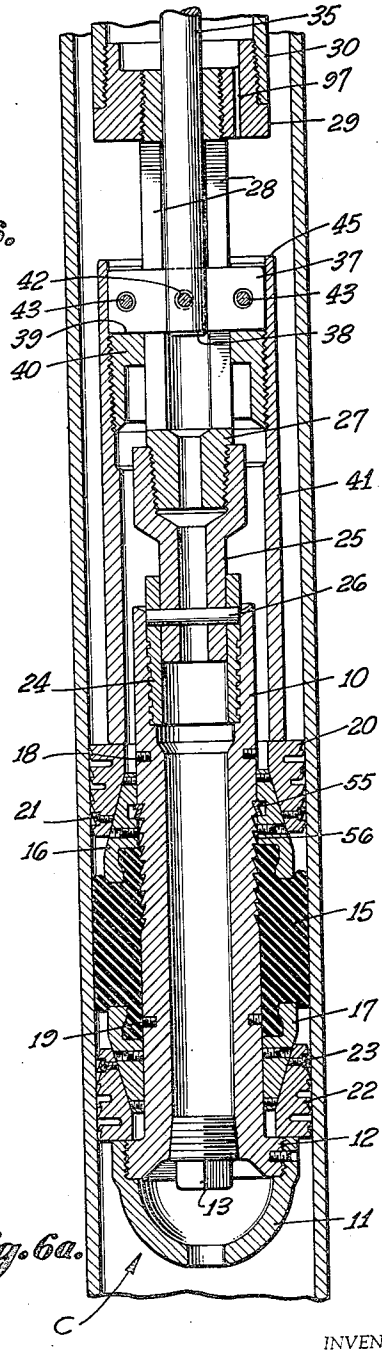

Fig. 6a.

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Fig. 7.

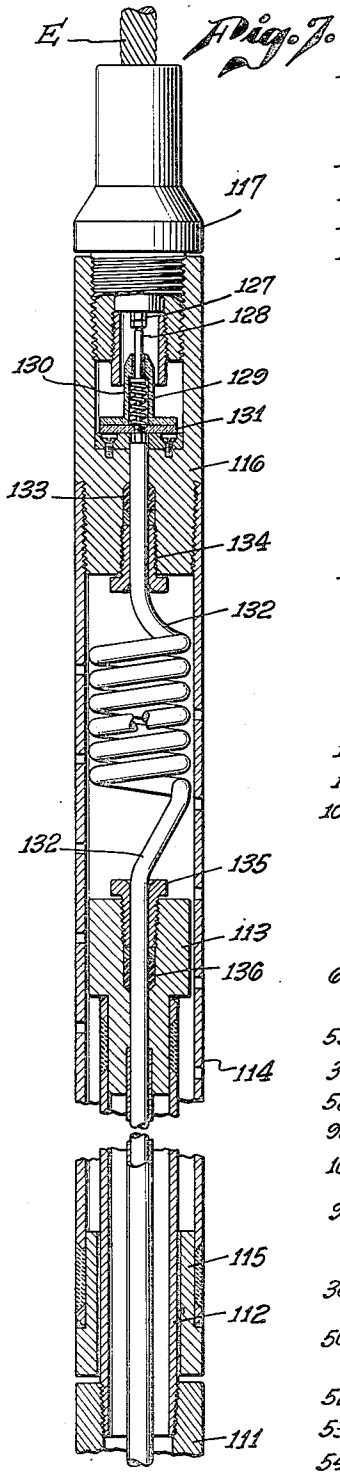


Fig. 7a.

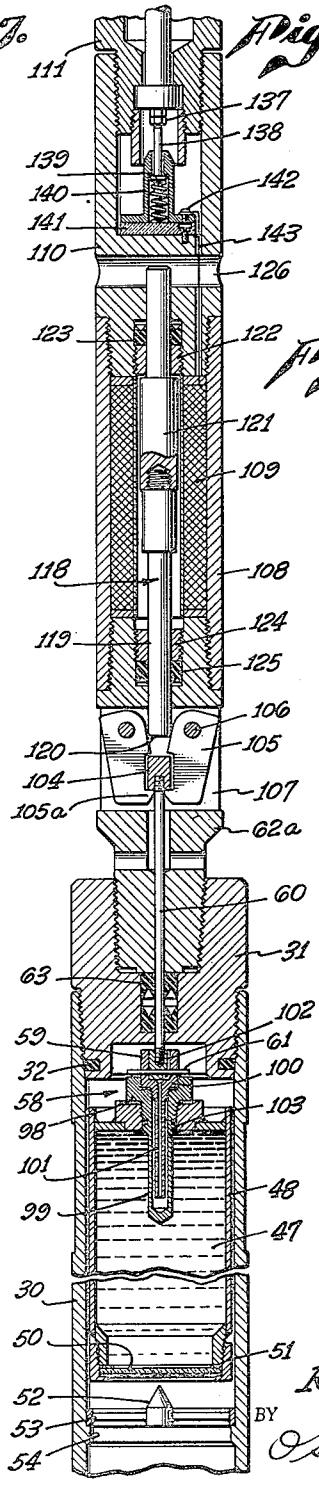
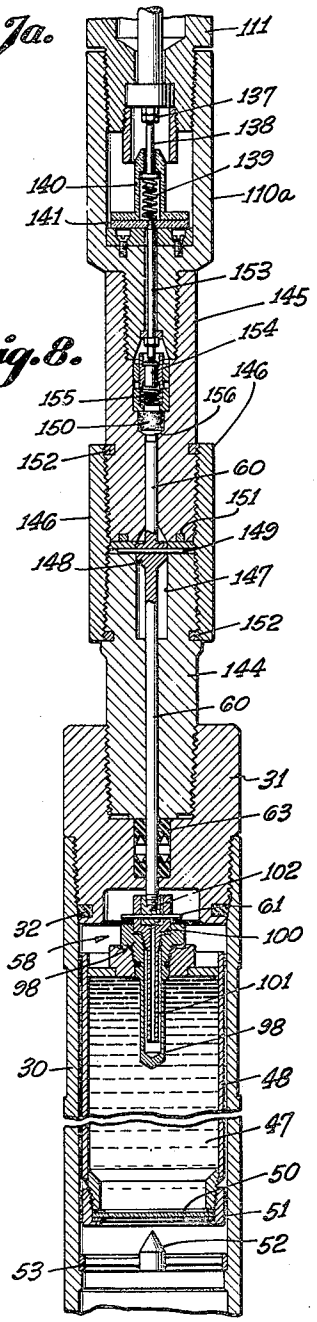


Fig. 8.



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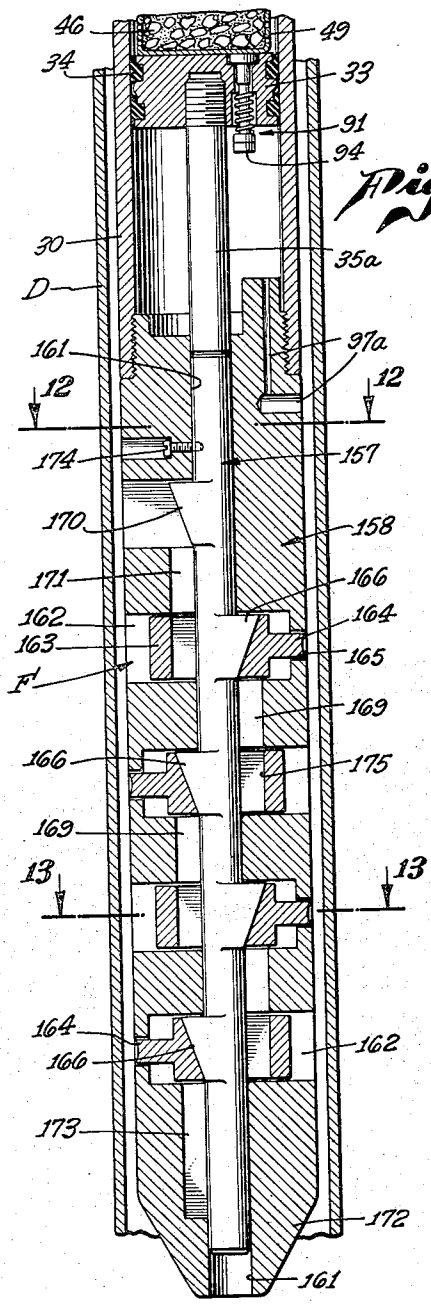

Fig. 9.

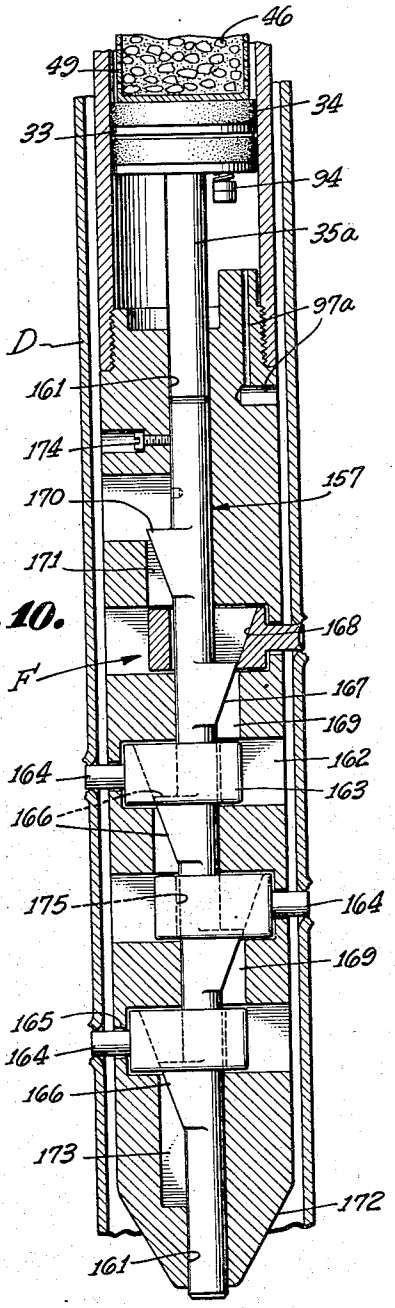

Fig. 10.

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MEANS FOR OPERATING WELL APPARATUS

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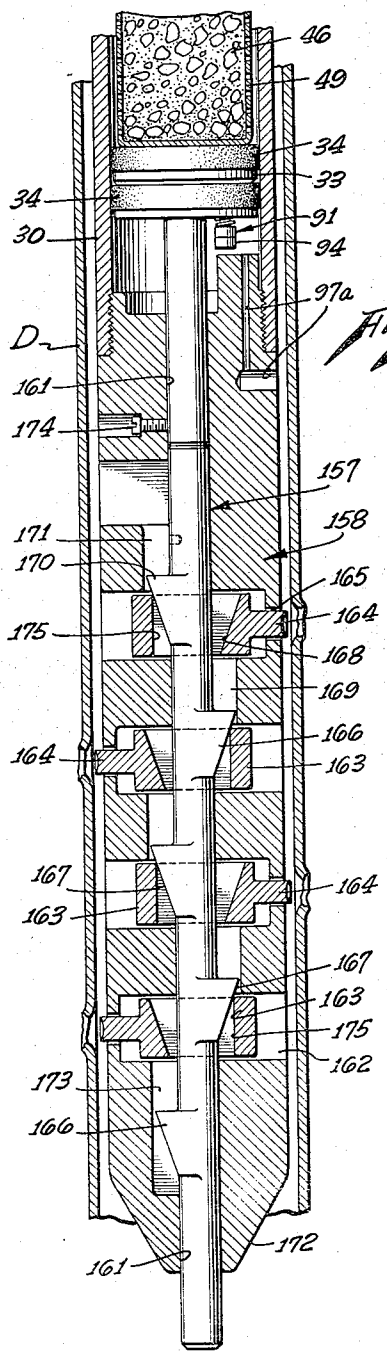

Fig. 11.

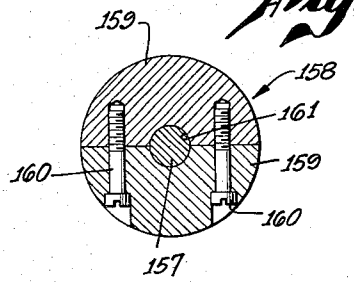

Fig. 12.

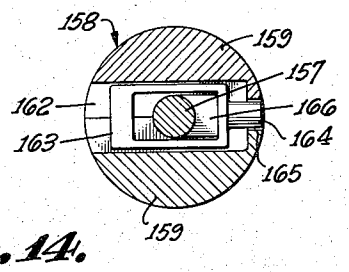

Fig. 13.

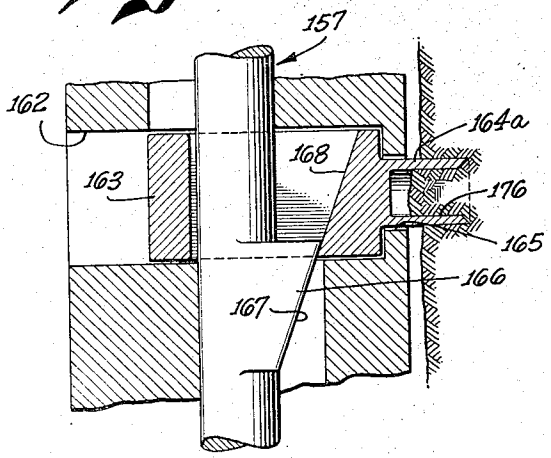

Fig. 14.

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Patented Apr. 3, 1945 2,373,006

UNITED STATES PATENT OFFICE

2,373,006

MEANS FOR OPERATING WELL APPARATUS

Reuben C. Baker, Coalinga, Calif., assignor to Baker Oil Tools, Inc., Vernon, Calif., a corporation of California

Application December 15, 1942, Serial No. 469,065

22 Claims. (Cl. 166—13)

The present invention relates to means for operating well apparatus, and is particularly concerned with operations conducted in bore holes, such as oil, gas and similar wells. Various types of apparatus are lowered in a well bore on a running-in string, such as a wire line, to a predetermined point where the apparatus is to be operated. The operation of the particular equipment may be sudden and violent, as when the device is actuated explosively, or requires the application of a strain on the running-in string to effect its full performance in the well bore. In the case of well packers, especially those lowered through the well bore on the end of a wire line, large strains are placed on the wire line to set the packer fully. Attempts at avoiding such strains have resulted in incomplete and insecure setting of the packers, as when reliance is made on the well pressures to fully set the packers and retain them in such set positions. In any event, the setting action is sudden and violent, and offers many disadvantages usually associated with the rapid movement of mechanical elements.

It is an object of the present invention to overcome the aforementioned difficulties by providing means for operating well apparatus by fluid pressure forces that are gradually generated when desired at the location of the apparatus in the well bore.

Another object of the invention is to provide improved means for operating well apparatus adapted to be lowered in a well bore on a running-in string, in which full and complete operation of the apparatus requires or imposes substantially no strain or strains on the running-in string.

Still a further object of the invention is to provide an improved apparatus capable of firmly and securely setting a well packer, such as a bridge plug, in a well bore or casing with a predetermined maximum setting force and without imposing strains on the wire line by which such apparatus and plug are usually run in the well bore. As a further aspect of this objective, the maximum setting force is created and approached gradually, rather than suddenly, and is controlled to release the setting apparatus automatically from the bridge plug, so as to permit its removal from the well bore.

The invention contemplates the gradual generation of fluid pressure from chemical reaction between two or more substances which are prevented from contacting one another until such time as it is desired to operate the particular apparatus being employed in the well bore. Such fluid pressure is created at the location of the apparatus in the well bore, and furnishes a source of energy which is gradually built up and gradually applied to the device employed in the well bore.

The fluid pressure may be created through the reaction of an acid material and a base metal, or through the reaction of an acid material and the carbonate or bicarbonate salt of a base metal, or combinations thereof, or through the chemical reaction between any substances capable of producing a pressure stable gas. By a pressure stable gas is meant a gas which is not decomposed by the application of pressure alone. Any chemically reactive substances may be used to build up either gaseous or liquid fluid pressure, so long as the substances are initially kept from one another, being permitted to contact and chemically react whenever the pressure is to be generated. Specific examples of chemically reactive substances capable of achieving applicant's objectives are set forth later in this specification.

This invention has other objects that will become apparent from a consideration of the embodiments shown in the drawings accompanying and forming part of the present specification. These embodiments will now be described in detail, to illustrate the principles of the invention, but it is to be understood that such detailed description is not to be taken in a limited sense, since the scope of the invention is best defined by the claims appended hereto.

Referring to the drawings:

Figure 1 is an elevational view of one form of apparatus within a well bore;

Figure 2 is a longitudinal section disclosing the upper part of the apparatus shown in Figure 1;

Figure 2*a* is a longitudinal section illustrating the intermediate part of the apparatus disclosed in Figure 1;

Figure 2*b* is a longitudinal section disclosing the lower part of the apparatus illustrated in Figure 1;

Figure 3 is a cross section taken along the line 3—3 in Figure 2;

Figure 4 is a cross section taken along the line 4—4 in Figure 2*a*;

Figure 5 is a cross section taken along the line 5—5 in Figure 2*b*;

Figures 6 and 6*a* are longitudinal sections corresponding to Figures 2*a* and 2*b*, but disclosing the apparatus in another operative position;

Figure 7 is a longitudinal section of the upper

portion of a modified form of tripping device employable in connection with well apparatus, such as that disclosed in Figure 1;

Figure 7a is a longitudinal section of the lower portion of a tripping device, forming a lower continuation of Figure 7;

Figure 8 is a longitudinal section through still another embodiment of the tripping device employable in connection with well apparatus, such as that disclosed in Figure 1.

Figure 9 is a longitudinal section through another embodiment of the invention;

Figure 10 is a view similar to Figure 9, illustrating the apparatus with its parts in another operative position;

Figure 11 is a view similar to Figure 9, disclosing the apparatus with its parts in still another operative position;

Figure 12 is a cross section taken along the line 12—12 in Figure 9;

Figure 13 is a cross section taken along the line 13—13 in Figure 9; and

Figure 14 is a partial section of a modification of the apparatus shown in Figures 9, 10 and 11.

The form of the invention disclosed in Figures 1 to 6a, inclusive, has been devised particularly as a wire line bridge plug apparatus. In general, such apparatus includes an upper tripping device A, an intermediate setting device B, and a lower packer or bridge plug C connected to the lower end of the setting device. The packer is to be anchored in packed-off condition within a well casing D through which the entire apparatus can be lowered on the end of a wire or other flexible line E.

The particular bridge plug C illustrated in the drawings (see Figures 2b and 6a) is of a known design and is specifically described in each of several United States patents, such as Nos. 2,121,051 and 2,204,648. Essentially it consists of a tubular body 10 having a guide 11 threaded on an abutment 12 at its lower end and a plug 13 screwed into its central passage 14 to prevent fluid flow therethrough in both directions. A packing sleeve 15 is disposed around the body, and is coupled at its ends to upper and lower tapered expanders 16, 17 slidably mounted on the body 10. These expanders are initially secured to the body by sheer screws 18, 19 so as to hold the packing sleeve 15 in retracted position. A set of upper segmental slips 20 is disposed around the body and is initially secured to the upper expander or cone 16 by shear screws 21, while a lower set of segmental slips 22 is disposed around the body 10 and is secured to the lower expander 17 by shear screws 23. The upper slips 20 are cooperable with the upper expander 16 and engageable with the casing to prevent upward movement of the packer, while the lower slips 22 are cooperable with their expander 17 and engageable with the casing wall to prevent downward movement of the packer, as shown in Figure 6a.

The setting tool B of the apparatus is secured to the bridge plug C in such manner that the setting force generated by the chemical reaction between substances contained within the setting tool is transmitted to the bridge plug to anchor it firmly and securely in the well casing. As disclosed in the drawings, a sleeve 24 is threaded in the upper end of the packer body 10 and receives a shear plug 25 which is secured to the sleeve by a shear pin 26 extending through both the sleeve and plug. A generally tubular actuating mandrel 27 is threadedly attached to the shear plug and is provided with longitudinally extending slots 28. The upper end of this mandrel is threaded into a lower cylinder head 29, which, in turn, is threaded into the lower end of a cylinder 30, the upper end of which is closed by an upper cylinder head 31. Leakage between the upper head and cylinder is prevented by a thread seal 32.

A piston 33 is slidable within the cylinder and has suitable piston rings 34 on its periphery to prevent leakage in a downward direction between it and the wall of the cylinder. This piston is attached to a piston rod 35 extending downwardly into the bore 36 of the actuating mandrel 27, where it receives an anvil or cross piece 37 in a slot 38 at its lower end which extends in opposite directions through the longitudinal slots 28 in the mandrel and into adjacent radial slots 39 provided in a setting ring 40 slidable on the mandrel 27, to which is threadedly attached a slip setting sleeve or skirt 41 extending downwardly for engagement with the upper set of packer slips 20. Disassembly of the anvil 37 from the piston rod 35 is prevented by a pin 42. Similarly, pins 43 extending through the setting ring 40 and anvil 37 prevent their disassembly, while removal or loss of these latter pins 43 is prevented by the fact that the holes 44 in the setting ring through which they extend are encompassed by the upper portion 45 of the setting sleeve 41.

Pressure can be created at the high pressure or upper end of the piston 33 and cylinder 30 through the chemical reaction between suitable substances. As disclosed in the drawings, one of the substances 46 may be contained in the cylinder immediately above the piston, and the other substance 47 can be initially retained in a container 48 so that it is kept free from contact with the other reacting substance until such time as fluid pressure within the cylinder is to be generated. For convenience of description, specific reference will be made at this time to certain chemical compounds and elements that have actually been employed to create the desired pressures, but it is to be understood that many other operable substances may similarly be employed in their place.

Zinc shavings 46 are placed in the cylinder 30 in loose fashion on top of the piston 33, or they may be contained loosely for convenience in a perforated basket 49, which is lowered into the cylinder and rests upon the piston. The upper container 48 is filled completely with hydrochloric acid 47 which is held therewithin and prevented from commingling with the zinc shavings 46 by closing the lower end of the container with a destructible glass or other closure 50 secured to the lower end of the container by a clamp ring 51. When commingling between the hydrochloric acid and zinc shavings is desired, the bottom closure 50 of the container 48 is destroyed in any suitable manner, as by lowering the container and forcing the closure onto a point 52 forming the hub of a spider like ring 53 seating on an internal shoulder 54 in the cylinder. Upon breaking the closure, the hydrochloric acid in the container 48 flows over and reacts with the zinc shavings to produce hydrogen gas. The proportions and quantities of zinc shavings and hydrochloric acid are such that a comparatively high unit pressure can be generated or developed, of more than sufficient extent to set the packer C in the well casing D.

As the pressure increases, due to the increased evolution of hydrogen gas, the piston 33 and its

connected rod 35 are forced downwardly within the cylinder 30 to move the anvil or cross piece 37 downwardly within the slotted actuating mandrel 27, and correspondingly move the setting ring 40 and setting sleeve or skirt 41 against the upper set of slips 20. The pressure is also acting upwardly on the cylinder head 31 and cylinder 30, which is connected through the actuating mandrel 27, shear plug 25, shear pin 26, and shear sleeve 24 to the packer body 10. As a result, the fluid pressure being generated in the cylinder is causing the piston 33 to exert a downward force on the upper set of slips 20, through the setting sleeve 41, and an upward force on the packer body 10, through the cylinder 30, mandrel 27, and parts 25, 26, 24 connecting the mandrel to the body 10.

When the pressure increases sufficiently to shear the screws 21 securing the upper slips 20 to the upper expander 16, these upper slips 20 are moved downwardly on this expander and outwardly into engagement with the casing. As the pressure increases further, the shear screws 18 holding the upper expander 16 to the body are disrupted, since the upper conical expander is prevented from moving upwardly by its associated casing engaging slips 20, and the packing 15 is shortened and compressed between the cones 16, 17 for expansion outwardly into sealing engagement with the wall of the casing. Further increase in the fluid pressure in the cylinder resulting from the reaction between the hydrochloric acid and zinc shavings shears the screws 19 holding the lower expander 17 to the body 10 and the screws 23 holding the lower slips 22 to the lower expander, causing the abutment 12 at the lower end of the body to move the lower slips 22 upwardly along its cooperable expander 17 and outwardly into anchoring engagement with the casing. The packer or bridge plug C is now firmly and securely anchored in packed off condition within the well casing, and will be retained in such condition by the locking of a split ratchet ring 55 within the upper cone 16 with circumferential ratchet teeth 56 on the exterior of the body 10. (See Figure 6a.)

High pressures can be generated within the cylinder 30, such pressures preferably being higher than those actually necessary to set the packer C firmly and securely in the casing D. It is preferred, however, to limit the maximum setting pressure and also to disconnect the setting device B automatically from the well packer after it has been anchored within the casing, so as to permit withdrawal of the entire mechanism above the packer from the well bore. For this reason, the shear plug 25 forming the lower end of the setting device is connected to the shear sleeve or sub 24 through the shear pin 26. This pin 26 has a predetermined shear value, and when the pressure increases sufficiently in the cylinder, the upward force exerted on the cylinder 30, actuating mandrel 27, and shear plug 25 shears the pin 26 and automatically disconnects the shear plug 25 from the sub 24. As can be seen from the drawings, the entire mechanism A, B will then be disconnected from the packer.

As disclosed in the drawings, the acid container 48 is initially held in elevated position within the cylinder a short distance above the closure breaker 52, 53 by suspending it from a releasing mechanism 57. A central plug device 58 is threaded into the upper end of the container 48, which is, in turn, secured to a head 59 threaded on a lower plunger or rod 60 by a coupling pin 61. This rod 60 extends upwardly through the upper cylinder head 31 and into a trip or lock sleeve 62 threaded into the cylinder head. Leakage in both directions between the rod 60 and cylinder head 31 is prevented by the opposed rod packings 63. The lower rod 60 is threadedly secured to a larger trip rod 64 having a longitudinal slot 65 therethrough.

A pair of latches 66 is mounted in the slot 65 on a pivot pin 67 secured to the upper rod 64 and extending across its slot. These latches 66 project in opposite directions and have detents 68 formed on their foot portions engageable with the lower ends of opposed longitudinal slots 69 in the lock sleeve 62, to prevent downward movement of the trip rod 64, the lower rod 60, and the container 48 attached thereto. The latches 66 are also provided with oppositely directed arms 70, 71 extending outwardly through the locking sleeve slots 69. Each latch has a light arm 71 projecting upwardly, which is held in this position with the detent 68 locked against the lower end of the slot 69 by an opposite heavy arm 70 on the latch. As additional assurance that the detents will not be moved inadvertently from their locked position, the latches may be secured together by a shear screw 72. The latching device just described is claimed in my application for "Trip device for well apparatus," Serial No. 411,801, filed September 22, 1941, now Patent No. 2,330,258, granted September 28, 1943.

A perforated barrel 73 forming part of a telescopic jarring mechanism is secured, as by welding, to a connecting pin 74 that is threaded into the trip sleeve 62. A head 75 is threaded on the upper end of this barrel. The inner part of the telescopic jar consists of an inner mandrel 76 having a lower mandrel head 77 adapted to engage the upper barrel head 75 when the telescopic jar is activated upwardly to deliver a blow to the barrel 73, and through the connecting pin 74 to the lower members of the apparatus. The threading of a sinker bar 78 of sufficient weight on the upper end of the mandrel 76 permits downward jarring to take place through its ability to contact and deliver a blow downwardly on the barrel head 75 and barrel 73.

The upper end of the sinker bar 78 is threaded into a pin joint 79 that is also threaded in a socket 80 adapted to receive and be secured to the lower end of the wire line E in any suitable manner. As shown in the drawings, such connection is effected by providing segmental slips 81 having outer tapered surfaces 82 and inner wickered surfaces 83 adapted to grip the wire line E. The outer tapered surfaces 82 are cooperable with a companion tapered surface 84 in the socket body 80 into which the pin joint 79 is threaded. The upper end 85 of the pin joint engages the slips 81 to force them towards the convergent end of the body taper 84 and radially inwardly into gripping engagement with the wire line E. Through the wire line E, and its connection to the socket 80, the entire mechanism may be lowered in the well bore, and also removed therefrom, with the exception of the anchored bridge plug C.

An actuator 85a for moving the acid container 48 relatively downwardly is mounted on the telescopic barrel 73. Such actuator consists of a friction device composed of a plurality of outwardly bowed springs 86 adapted to frictionally engage the wall of the casing. The upper and lower ends of the springs are secured to spaced apart collars 87, 88 slidable on the barrel 73, by

encompassing rings 89 suitably attached to the collars, as by screws 90.

In lowering the apparatus through a well casing to the desired setting point, the friction of the springs 86 against the casing causes the actuator 85a to remain in elevated position on the barrel 73 of the jarring mechanism (see Figure 2). However, upon reaching the region in which the bridge plug or packer C is to be set, the wire line E is elevated a sufficient distance to elevate the entire mechanism, with the exception of the friction actuator, which tends to remain stationary because of the frictional resistance that the springs 86 offer against the wall of the casing C. Elevation of the entire mechanism sufficiently causes the lower friction collar 88 to engage the light arms 71 of the latches 66 and swing them on their pivot 67 to remove the detents 68 from the lower ends of the trip sleeve slots 69. If a shear screw 72 is employed between the latches, it is first disrupted and the latches then swung on their pivot pin 67 in the manner described. Further elevation of the wire line E and the mechanism secured thereto causes the friction device 85a to force the latches 66 and their connected rods 64, 60 and container 48 downwardly so as to press the closure 50 against the breaker point 52 and produce its destruction, thereby enabling the acid 47 in the container to commingle with the zinc shavings 46, in the manner aforementioned. Upon sufficient pressure being generated in the cylinder, the packer is fully set, as described above, the maximum setting force being determined by disruption of the shear pin 26, which automatically disconnects the tripping and setting mechanism from the bridge plug and allows their withdrawal from the well bore.

In the event that sufficient pressure is not generated in the cylinder 30 to effect disruption of the shear pin 26, and consequent disconnection of the tripping and setting device A, B from the bridge plug C, the telescopic jar can be manipulated to deliver a blow, either downwardly through the falling action of the sinker bar 78 on the barrel head 75, or upwardly through engagement of the mandrel head 77 with the barrel head 75, which blow is directed through the barrel 73, connecting pin 74, tripping sleeve 62, upper cylinder head 31, cylinder 30, lower cylinder head 29, actuating mandrel 27, and shear plug 25 to the shear pin 26. Blows of sufficient force can be imparted to the apparatus to disrupt this shear pin should its disruption by fluid pressure be unobtainable. It is to be understood that ordinarily the fluid pressure generated is of sufficient degree to disrupt the pin 26, the jarring mechanism being provided solely as a precautionary measure.

It is preferred to exclude air from the cylinder 30 and container 48, and also to equalize the hydrostatic pressure within the cylinder and container with that externally of the device as the tool is being lowered through any fluid that might be present in a well bore.

Air may be excluded by completely filling the container 48 with acid, and by filling the voids between the zinc shavings and the remainder of the space in the cylinder around the container with a liquid that does not react with the zinc shavings.

The hydrostatic pressure may be balanced by providing an equalizing valve 91 in the piston 33, consisting of a valve seat 92 at the upper high pressure end of the piston adapted to be engaged by a valve head 93 having a spring retainer 94 threaded on its stem 95 against which a spring 96 bears in order to tend to hold the valve downwardly in closed position. As the apparatus is lowered in the well bore, the hydrostatic fluid head or pressure therein may exert itself on the fluid within the cylinder 30 by the passage of fluid through the vent hole 97 in the lower cylinder head 29 to the low pressure end of the cylinder, from where the fluid can open the one way equalizing valve 91 against the resistance of its spring 96 and pass into the cylinder.

The hydrostatic pressure is also equalized by being imposed upon the acid 47 within the container 48. The plug device 58 at the upper end of the container is made generally in two parts, namely, an outer plug 98 threaded into the upper end of the container 48 having a depending tube 99 closed at its lower end, and an inner plug 100 secured to the lower trip rod 60, which is threaded into the outer plug 98 and has a depending equalizer tube 101 extending into the outer tube 99. The inner tube 101 communicates with the cylinder externally of the container 48 by virture of the clearance space 102 between the rod head 59 and inner plug 100, while the outer tube 99 is in communication with the inner tube at its lower end and also with the interior of the container 48 through a vent 103 near its upper end. There is thus provided a tortuous path between the interior and the exterior of the container through which the pressure externally of the container is equalized internally thereof by being exerted through fluid in the clearance space 102, the inner tube 101, the annular space between the inner tube 101 and outer tube 99, and the vent 103, to the fluid within the container. Contamination or commingling between the fluid externally of the container and the acid therewithin prior to breaking of the cover 50 is prevented by filling the inner and outer tubes 101, 99 with some dormant liquid, such as lubricating oil. This oil functions to transmit pressure through the tortuous path, but will not be displaced from its position within the tubes.

Not only does the valve 91 in the piston 33 function to equalize the pressure internally of the cylinder and its associated elements with the hydrostatic head externally thereof, but it also functions as a relief valve upon disruption of the shear pin 26 securing the shear plug 25 to the packer C. When this shear pin breaks under the action of the fluid pressure within the cylinder, the piston 33 is free to move downwardly to its fullest extent, which is determined through engagement of the piston with the upper annular portion of the lower cylinder head 29. However, before such engagement occurs, the valve spring retainer 94 engages the upper end of the actuating mandrel 27 and lower head 29 to open the valve against the action of its spring 96 and permit the pressure within the cylinder 30 to be dissipated through the valve 91 and vent hole 97 into the well bore. When the tripping and setting portions A, B of the apparatus are removed to the surface of the hole, such pressure will be substantially atmospheric and thereby permit the tool to be disassembled with safety.

The substances employed in the cylinder 30 and container 48 may be suitably chosen and used in various proportions. In one actual use of the device shown in the drawings, about forty ounces of zinc shavings were provided in the cylinder, and this was caused to react with about one gal-

lon of approximately 35% hydrochloric acid placed in the container. The voids between the zinc shavings and the remaining space in the cylinder could have been filled with water, but greater final pressures were developed when the remaining fluid consisted of a saturated solution of sodium bicarbonate. In the device actually constructed and used, about one gallon of a saturated solution of sodium bicarbonate was sufficient to completely fill the remaining spaces in the cylinder, so as to exclude all air.

When the closure 50 on the container 48 was broken, hydrochloric acid reacted with the zinc shavings, and apparently also with the sodium bicarbonate, to generate hydrogen gas essentially, and also some carbon dioxide. The shear screw was of such dimensions and of such material as to break when about 2000 p. s. i. pressure was generated within the cylinder 30. The piston 33 possessed an area of about 15 square inches, so that the final setting force on the bridge plug C was a total of 30,000 pounds. Actually, the pressure potential within the cylinder was much greater, but the maximum pressure reached was 2000 p. s. i., as determined by shearing of the pin 26, which permitted the piston 33 to move downwardly to its fullest extent and caused the relief valve 91 to open. As was stated above, the final pressure that can be generated is dependent upon the materials used and their relative proportions.

In the actual case given above, complete setting of the packer C and disruption of the shear pin 26 occurred in about ten minutes with a surrounding temperature of about 75° F. Higher well temperatures would have accelerated the reaction and would also increase the maximum pressure obtainable with a given quantity of zinc, hydrochloric acid, and sodium bicarbonate.

Further examples of substances employable in the cylinder 30 are the reacting of aluminum, iron, cadmium, mercury, magnesium, calcium, sodium, or potassium, etc., with a suitable inorganic or organic acid, such as hydrochloric, sulphuric, nitric, acetic, citric, etc. It is, of course, also possible to react aluminum with sodium hydroxide and water, and sodium or potassium with water. Various filling solutions can be used to fill the spaces remaining in the cylinder after placement of the reacting substance therein, in addition to water or a saturated solution of sodium bicarbonate, so long as such filling solution does not react with the base metal inserted at the top of the piston. This filling solution may or may not react with the acid, as desired, although it is preferred that it do so whenever it will assist in producing the desired fluid pressure. Premature reaction of an active filling solution with the acid will not occur, since commingling of the acid in the container and the fluid externally thereof is prevented by the inert liquid in the inner and outer pressure equalizing tubes 101, 99.

Figures 7 and 7a together disclose a modified form of tripping apparatus for producing breaking of the acid container cover 50. Instead of moving the container downwardly mechanically, as described in connection with Figures 1 to 6a, inclusive, it is moved downwardly through electrical mechanisms.

The tripping rod or plunger 60 to which the container 48 is secured is held in elevated position by threading it into a lock 104 (see Figure 7a), which is prevented from moving downwardly under the influence of gravity by lower detents 105a on latches 105 mounted on pivot pins 106 within a longitudinal slot 107 in a trip or lock sleeve 62a secured to the upper cylinder head 31 and into which the trip rod 60 extends. The upper end of the trip sleeve 62a is threaded into a solenoid housing 108 containing a solenoid coil 109. The upper end of this housing is threaded onto a terminal housing and guide plug 110, whose upper end is threaded onto a connecting pin 111 secured to a mandrel 112 having a head 113 welded on its upper end.

The mandrel 112 and its head 113 form the inner portion of a telescopic jar whose outer portion is constituted by a perforated barrel 114, whose lower end is welded to a head 115. The upper end of the perforated barrel 114 is threaded on an upper barrel head 116 which is threaded onto a cable head 117, to which the lower end of a wire line conductor cable E is secured in any known and suitable manner. This conductor cable serves as the connecting link in moving the entire apparatus from the surface of the well bore, and also as the current carrying medium.

A solenoid plunger 118 extends upwardly from the lock 104 into and coaxially of the solenoid coil 109. The lower portion 119 of this plunger is made of non-magnetic material, such as brass or a synthetic resin, and has a lower cam or nose 120 initially elevated above the lock 104 resting on the latches 105. The lower plunger 119 is threaded into an upper magnetic plunger portion 121 that passes into the terminal housing 110 where a packing nut 122 holds a rod packing 123 in leak-proof relation against it. Similarly, a packing nut 124 is provided in the upper portion of the trip sleeve 62a to hold a rod packing 125 in sealing position against the non-magnetic solenoid plunger portion 119. The rod portions 119, 121 against which the rod packings 123, 125 seal are preferably equal in area so that the hydrostatic pressure of fluid within the well bore acting on the plunger is equalized in both directions. To permit pressure equalization, the terminal housing 110 is provided with a transverse opening 126 allowing fluid to act on the upper end of the solenoid plunger.

Current is transmitted from the conductive core of the conductor cable E to the solenoid coil 109 through several conductive elements connected in series. Thus, the conductor cable terminal 127 engages a trip terminal 128 urged against it by a spring 129 contained within a cap 130, preferably made of insulating material, which rests upon an insulating block 131. The current passes from the trip terminal 128 to the upper end of the insulated conductor 132, that passes through a packing 133 and packing nut 134 at the lower end of the upper barrel head 116 into the barrel 114, where it is coiled helically to provide a flexible or spring-like conductor. This flexible conductor 132 passes through a packing nut 135 and packing 136, into and through the mandrel head 113 until it terminates within the connecting pin 111 with its lower terminus 137 engaging a lower trip pin 138 yieldably urged thereagainst by a spring 139 contained within a conductor cap 140 fastened to an insulating block 141 mounted within the terminal housing 110. Current passes from the conductor cap through the binding post or screw 142 to a lead 143 running to one end of the solenoid coil 109. The circuit is completed by connecting the other end of the solenoid coil to the solenoid housing 108, the current passing upwardly through the metallic portions of the apparatus through the conductor cable enclosing

the conductor core, back to the source of electrical energy.

When it is desired to shift the acid container 48 downwardly to break its closure 50 and create pressure within the cylinder 30, the electric circuit is closed (e. g., at the well surface) to permit current to pass through the solenoid coil 109. The magnetic solenoid plunger 121 is drawn thereby downwardly within the solenoid coil, and moves the non-magnetic portion 119 downwardly to cause its cam 120 to swing the latches 105 outwardly on their pivots 106 and shift their detents 105a away from the lock 104 to release the rod 60. Continued downward movement of the plunger 118 then engages the cam 120 with the plunger lock 104 and shifts the plunger rod 60 and acid bottle 48 downwards to break the closure 50 against the point 52 of the spider 53.

Should it be necessary to perform a jarring action on the cylinder 30 and the parts rigidly attached thereto to break the frangible pin 25, the conductor cable E may be elevated to raise the outer barrel 114 with respect to the inner mandrel 112. The helical form of the flexible conductor 132 will permit such action to occur through its spring-like distention. The conductor cable may thus be dropped so that the lower barrel head 115 strikes a blow on the connecting pin 111, which is transmitted through the terminal housing 110, solenoid housing 108, trip sleeve 62a and cylinder head 31 to the cylinder 30, from where the force of the blow travels through the actuating mandrel 27 and shear plug 25 to the shear pin 26. Repeated blows may be thus struck until the shear pin 26 is broken.

Another device for moving the acid container 48 downwardly to effect breaking of its closure 50 is disclosed in Figure 8. The same electrical jarring apparatus can be used as illustrated in Figure 7, the terminal connection disclosed at the top of Figure 8 being substantially the same as that shown at the top of Figure 7a.

The container 48 is moved downwardly by explosive forces that are controlled electrically. The plunger or trip rod 60 extending upwardly from the container passes through a lower gun barrel 144 threaded into the upper cylinder head 31, which is secured to an upper gun barrel 145 through an intermediate threaded coupling 146. A coaxial bore or space 147 is provided at the upper end of the lower gun barrel 144 in which is slidably received an intermediate enlargement or head 148 on the trip rod 60. A shear pin 149 extends through this head and into the lower gun barrel on opposite sides of its bore 147 to hold the trip rod 60 and the container 48 attached thereto initially in elevated position.

The trip rod 60 extends upwardly from this head 148 into the upper gun barrel 145, in effect functioning as a piston on which a powder charge 150 is effective when the explosion occurs. Leakage between the trip rod 60 and upper and lower gun barrels 145, 144 is prevented by a packing 151 in the upper barrel engaging the upper end of the lower barrel 144. As additional assurance against such leakage, thread seals 152 may be provided between the coupling collar 146 and barrels at its opposite ends. The upper gun barrel 145 is threaded onto the lower end of a terminal housing 110a, which is threaded onto a connecting pin 111 in the manner described in conjunction with Figures 7 and 7a.

Current is conducted from the lower trip terminal 138 through a lead 153 extending through the lower end of the terminal housing 110a, where it contacts an electric detonator 154 held in contact therewith by a coil spring 155. This electric detonator contains a small powder charge and a filament (not shown). Positioned below the detonator 154 and above the piston end of the trip rod is the powder charge 150, contained within the upper gun barrel chamber 156.

When it is desired to break the closure 50 of the acid container 48, the circuit through the electric detonator 154 is completed and the resulting detonation sets off the powder charge 150. Gases are generated by the explosion at sufficient pressure to shear the pin 149 and move the trip rod 60 downwardly, thereby forcing the container 48 in the same direction and breaking the closure 50 on the spider point 52. Commingling of the acid and the other substances in the cylinder 30 causes the chemical reaction to take place, and the generation of gas at sufficient pressure in the cylinder to set the bridge plug C, or any other apparatus employed in its place.

Figures 9 to 13, inclusive, disclose the invention in connection with a casing perforator F. In this embodiment the piston rod 35a extends directly downwardly from the piston 33 to act upon an elongated actuator 157, and the cylinder 30 is threaded, or otherwise suitably attached, directly to the cylindrical body 158 of the casing perforator.

The casing perforator F includes the aforementioned body 158, preferably formed in longitudinal halves 159, 159 secured together, as by screws 160 or the like, to form the complete rigid body unit. The body is made in halves to facilitate assembly of the parts contained within it. It is formed with a central longitudinal passage 161 in which the actuator 157 is positioned, and also with longitudinally spaced transverse slots 162 intersecting the passage to serve as guides for yoke-like slides 163 whose plunger perforator elements 164 are adapted to extend through openings 165 in the wall of the body 158. The actuator 157 extends through the slides 163 and has a plurality of oppositely facing axial cams 166 thereon possessing downwardly and inwardly inclined tapered surfaces 167 cooperable with companion tapered surfaces 168 in the slides.

It is preferred that a plurality of slides 163 be provided in the body in longitudinally spaced relation, and that a corresponding number of cam elements 166 be provided on the actuator 157. The slides 163 and their plunger perforators 164 extend alternately in opposite directions, being shown in the drawings as four in number, although it is to be understood that one or more of such slides in any reasonable quantity may be employed.

A longitudinal recess 169 merging into the longitudinal body passage 161 extends between the slots 162 below the tapered slide portions 168 to permit the cams 166 on the plunger actuator 157 initially positioned thereabove to pass from one slide into another, for a purpose to be described hereinafter. The actuator 157 is also provided with an additional tapered cam 170 facing in the opposite direction from the cam engaged with the uppermost slide, and this additional cam is adapted to pass through a longitudinal recess 171 extending upwardly from the uppermost transverse slot.

The lower portion of the body 158 is suitably tapered to serve as a guide 172 when the tool is run in the well bore, and the passage portion receiving the lower end of the plunger actuator 157 also merges into a recess 173 below the low-

ermost slide in line with its associated cam to permit this cam to move downwardly when the actuator is moved downwardly under the influence of the piston 33 and its rod 35a.

The tool with the zinc shavings 46 and acid 47 is run in the well casing in the same manner as was described in connection with Figures 1 to 8, inclusive, until the desired position is reached in which holes or perforations are to be punched through the casing wall. All of the slides 163 are in their retracted position, as disclosed in Figure 9, and the elongated actuator 157 is held in its uppermost position by suitable means, such as a shear screw 174 extending through the body into the plunger actuator, in order to hold the cams 166 fully engaged with the corresponding tapered slide surfaces 168. When it is desired to perforate the casing, the acid is allowed to commingle with the zinc, as previously described, and the resultant gaseous pressure exerts downward force on the piston 33, producing shearing of the screw 174 and downward motion of the actuator 157. Such downward movement of the latter member causes its cam elements 166 to force the slides 163 laterally outwardly and their associated plunger perforators 164 against and through the wall of the casing, as disclosed in Figure 10.

Continued downward movement of the piston 33 and actuator 157 eventually removes the cams 166 from the cooperable tapered surfaces 168 of the slides and shifts them through the longitudinal recesses 169 into engagement with the rears 175 of the lower slides. The tapered surfaces 167 on such cams retract these slides 163 as the actuator 157 continues to move downwardly, as disclosed in Figure 11, effecting complete withdrawal of the plunger perforators 164 from the casing and back into the body 158 of the tool, thereby permitting removal of the entire apparatus from the well casing.

It should be noted that the uppermost cam 170 effects retraction of the slide and perforator element immediately therebelow, and that the cam 166 which forced the uppermost perforator 164 outwardly is effective to retract the perforator immediately therebelow, and that the cam which moved this latter perforator outwardly is effective to retract the third perforator immediately below it, and so on, all of the perforators being removed simultaneously to retracted position.

When the slides 163 and plunger perforators 164 have all been moved to retracted position, the piston 33 will have moved downwardly to a sufficient extent to cause opening of the equalizer valve 91 through engagement of its stem 94 with the upper end of the body 158, relieving the pressure in the cylinder by allowing the gases to escape through the open equalizer valve 91, and through the vent holes 97a in the upper end of the body. These holes 97a are also the means for equalizing the hydrostatic pressure within the cylinder with that externally of the tool as it is lowered in the well bore.

A modification of the apparatus disclosed in Figures 9 to 13, inclusive, is shown in Figure 14, wherein each plunger perforator is made hollow or formed as an outwardly opening tube 164a providing a chamber 176 capable of receiving a sample from the wall of the formation. The tool with the hollow perforators 164a is run in open hole until the desired sampling point is reached, whereupon actuation of the tool in the same manner as was described in connection with Figures 9 to 13, inclusive, causes the slides 163 and sampling tubes 164a to move outwardly, forcing the latter into the wall of the bore to wedge samples of the formation into the tubes. Continued downward movement of the piston 33 and actuator 157 effects retraction of the tubes from the bore wall back within the confines of the body, allowing the entire apparatus to be withdrawn from the well bore for examination of the samples.

It is therefore apparent that new means for operating subsurface well devices and apparatus have been described. The operations occur through the gradual building up of pressures that can, if desired, be of a comparatively high degree, without imposing sudden or violent shocks on the equipment employed, and with substantially no stresses or strains placed on a running-in string, such as a conductive or non-conductive wire line.

I claim:

1. Well apparatus, including a well device adapted to be operated in a well bore, fluid actuated means operatively connected to said well device, said fluid actuated means containing a base metal, a container within said fluid actuated means containing an acid separate from said base metal, means for releasing said acid from said container to enable it to react with said base metal and produce a gas for actuating said fluid actuated means, and means for substantially equalizing the pressure within said fluid actuated means and container with that externally thereof while the apparatus is being lowered in said well bore.

2. Well apparatus, including a well device adapted to be operated in a well bore, fluid actuated means operatively connected to said well device, said fluid actuated means containing a base metal, a container within said fluid actuated means containing an acid separate from said base metal, means for releasing said acid from said container to enable it to react with said base metal and produce a gas for actuating said fluid actuated means, and means for substantially equalizing the pressure within said fluid actuated means and container with that externally thereof while the apparatus is being lowered in said well bore comprising a passage in said container establishing communication between its interior and exterior.

3. Well apparatus, including a well device adapted to be operated in a well bore, fluid actuated means operatively connected to said well device, at least two dissimilar substances within said fluid actuated means capable of reacting chemically to produce a gas, a container in said fluid actuated means for confining one of said substances free from contact with the other substance, means for releasing said one substance from said container to enable it to contact said other substance and chemically react therewith to produce said gas, and means for substantially equalizing the pressure within said fluid actuated means and container with that externally thereof while the apparatus is being lowered in said well bore comprising a passage in said container establishing communication between its interior and exterior.

4. Well apparatus, including a well device adapted to be operated in a well bore, fluid actuated means operatively connected to said well device, at least two dissimilar substances within said fluid actuated means capable of reacting chemically to produce a gas, a container in said

fluid actuated means for confining one of said substances free from contact with the other substance, means for releasing said one substance from said container to enable it to contact said other substance and chemically react therewith to produce said gas, means for substantially equalizing the pressure within said fluid actuated means and container with that externally thereof while the apparatus is being lowered in said well bore comprising a passage in said container establishing communication between its interior and exterior, and a liquid in said passage for preventing commingling of the fluids internally and externally of said container prior to release of said one substance from said container.

5. Well apparatus, including a well device adapted to be operated in a well bore, fluid actuated means for operating said well device, at least two dissimilar substances within said fluid actuated means capable of reacting chemically with each other to produce a gas for actuating said fluid actuated means, means within said fluid actuated means for retaining one of said substances separate from the other substance, means for releasing said one substance from said retaining means to enable said substances to contact and chemically react to produce said gas, and means for automatically releasing said gas from said fluid actuated means upon completion of the operation of said well device in said well bore.

6. Well apparatus, including a well device adapted to be operated in a well bore, fluid actuated means for operating said well device, at least two dissimilar substances within said fluid actuated means capable of reacting chemically with each other to produce pressure stable gas for actuating said fluid actuated means, means within said fluid actuated means for retaining one of said substances separate from the other substance, means for releasing said one substance from said retaining means to enable said substances to contact and chemically react to produce said pressure stable gas, and one-way valve means in said fluid actuated means for substantially equalizing the pressure within said fluid actuated means with that externally thereof and for automatically releasing said gas from said fluid actuated means upon completion of the operation of said well device in said well bore.

7. Well apparatus, including a well device adapted to be operated in a well bore, fluid actuated means for operating said well device, at least two dissimilar substances within said fluid actuated means capable of reacting chemically with each other to produce a gas for actuating said fluid actuated means, and valve means operated by movement of said fluid actuated means for releasing said gas from said fluid actuated means.

8. Well apparatus, including a well device adapted to be operated in a well bore, a cylinder and piston for operating said well device, substances within said cylinder capable of reacting chemically with each other to produce a gas for moving said piston in said cylinder, and a valve on said piston operable upon movement of said piston in said cylinder for releasing said gas from said cylinder.

9. Well apparatus, including a well device adapted to be operated in a well bore, a cylinder and piston for operating said well device, substances within said cylinder capable of reacting chemically with each other to produce a gas for moving said piston within said cylinder, and means responsive to movement of said piston to a predetermined position within said cylinder for releasing said gas from said cylinder.

10. Well apparatus, including a well device adapted to be operated in a well bore, a cylinder and piston for operating said well device, substances within said cylinder capable of reacting chemically with each other to produce a gas for moving said piston within said cylinder, and a valve on said piston engageable with an end of said cylinder upon movement of said piston therewithin for releasing said gas from said cylinder.

11. Well apparatus, including a well packer having a body and normally retracted means for engagement with a well casing, fluid actuated means for setting said packer in said well casing comprising an upwardly movable cylinder and a downwardly movable piston within said cylinder, means within said cylinder above said piston for producing a gas therewithin for moving said piston downwardly within said cylinder, means cooperating with said piston for transmitting its downward movement to said normally retracted means, means including a frangible device for transmitting upward movement and force between said cylinder and body, and valve means operable upon downward movement of said piston within said cylinder for releasing said gas from said cylinder.

12. Well apparatus, including a well packer having a body and normally retracted means for engagement with a well casing, fluid actuated means for setting said packer in said well casing comprising an upwardly movable cylinder and a downwardly movable piston within said cylinder, means within said cylinder above said piston for producing a gas therewithin for moving said piston downwardly within said cylinder, means cooperating with said piston for transmitting its downward movement and force to said normally retracted means, means including a frangible device for transmitting upward movement and force between said cylinder and body, and an upwardly opening one-way valve on said piston for substantially equalizing the hydrostatic pressure internally and externally of said cylinder while said apparatus is being lowered through fluid in said well casing, said one-way valve engaging said cylinder upon downward movement of said piston to cause its opening and release of said gas from said cylinder.

13. Well apparatus, including a well packer having a body and normally retracted means for engagement with a well casing, fluid actuated means for setting said packer in said well casing comprising an upwardly movable cylinder and a downwardly movable piston within said cylinder, means within said cylinder above said piston for producing a gas therewithin for moving said piston downwardly within said cylinder, means cooperating with said piston for transmitting its downward movement and force to said normally retracted means, means including a frangible device for transmitting upward movement and force between said cylinder and body, and a valve on said piston engageable with said cylinder upon downward movement of said piston therewithin for releasing said gas from said cylinder, said valve engaging said cylinder after disruption of said frangible device.

14. Well apparatus, including a well packer having a body and slips for anchoring said body in a well bore, fluid actuated means for setting said packer in said well bore comprising a piston for exerting a downward force on said slips and a

cylinder for exerting an upward force on said body, means within said fluid actuated means for producing a gas therewithin at a pressure that is sufficiently high to cause said fluid actuated means to set said packer, frangible means for transmitting said upward force between said cylinder and body, said frangible means being disruptable upon application of a predetermined setting force on said body by said cylinder to automatically disconnect said fluid actuated means therefrom, and valve means responsive to relative movement between said cylinder and piston for releasing said gas from said fluid actuated means after disruption of said frangible means.

15. Well apparatus, including a well device having a body and normally retracted means for engagement with a well casing, fluid actuated means for setting said device in said well casing comprising a piston for exerting a downward force on said normally retracted means and a cylinder for exerting an upward force on said body, means within said cylinder for producing a gas therewithin at a pressure that is sufficiently high to cause said fluid actuated means to set said device, releasable means for transmitting said upward force between said cylinder and body, said releasable means automatically disconnecting said cylinder from said body upon application of a predetermined setting force by said cylinder on said body, and means controlled by movement of said piston within said cylinder for releasing said gas from said cylinder after said automatic disconnection of said releasable means.

16. Well apparatus, including a well device having a body and slips for anchoring said body in a well bore, fluid actuated means for setting said device in said well bore comprising a piston for exerting a downward force on said slips and a cylinder for exerting an upward force on said body, means within said fluid actuated means for producing a gas therewithin at a pressure that is sufficiently high to cause said fluid actuated means to set said device, and releasable means for transmitting said upward force between said cylinder and body, whereby said fluid actuated means may be disconnected from said body after setting of said device.

17. Well apparatus, including a well device having a body and slips for anchoring said body in a well bore, fluid actuated means for setting said device in said well bore comprising a piston for exerting a downward force on said slips and a cylinder for exerting an upward force on said body, means within said fluid actuated means for producing a gas therewithin at a pressure that is sufficiently high to cause said fluid actuated means to set said device, and frangible means for transmitting said upward force between said cylinder and body, said frangible means being disruptable upon application of a predetermined setting force on said body to automatically disconnect said fluid actuated means therefrom.

18. Well apparatus, including a well device having a body and normally retracted means for engagement with a well casing, fluid actuated means for setting said device in said well casing comprising a piston for exerting a downward force on said normally retracted means and a cylinder for exerting upward force on said body, means within said cylinder for producing a gas therewithin at a pressure that is sufficiently high to cause said cylinder and piston to set said device in said casing, and frangible means for transmitting said upward force between said cylinder and body.

19. Well apparatus, including a well device having a body and normally retracted means for engagement with a well casing, fluid actuated means for setting said device in said well casing comprising a piston for exerting a downward force on said normally retracted means and a cylinder for exerting upward force on said body, frangible means for transmitting said upward force between said cylinder and body, means within said cylinder for producing a gas therewithin at a pressure sufficiently high to cause said cylinder and piston to set said device in said casing and to disrupt said frangible means, and a jarring device connected to said cylinder.

20. Well apparatus, including a well device having a body and normally retracted means for engagement with a well casing, fluid actuated means for setting said device in said well casing comprising an upwardly movable cylinder and a downwardly movable piston within said cylinder, means within said cylinder above said piston for producing a gas therewithin for forcing and moving said piston downwardly within said cylinder, means cooperating with said piston for transmitting its downward movement and force to said normally retracted means, and means including a frangible device for transmitting upward movement and force between said cylinder and body.

21. Well apparatus, including a well device adapted to be operated in a well bore, fluid actuated means for operating said well device, at least two dissimilar substances within said fluid actuated means capable of reacting chemically with one another to produce a gas, a container movably mounted in said fluid actuated means for confining one of said substances free from contact with the other substance, means within said fluid actuated means for rupturing said container to allow contact between said substances and their chemical reaction with one another to produce said gas, and means for moving said container to force it against said rupturing means to release said one substance from said container.

22. Well apparatus, including a well device having a body and normally retracted means for engagement with a well casing, fluid actuated means for setting said device in said well casing comprising an upwardly movable cylinder and a downwardly movable piston within said cylinder, means within said cylinder above said piston for producing a gas therewithin for moving said piston downwardly within said cylinder, means cooperating with said piston for transmitting its downward movement and force to said normally retracted means, means including a frangible device for transmitting upward movement and force between said cylinder and body, and a vent at the lower end of said cylinder for permitting passage of fluid between its exterior and interior below said piston.

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