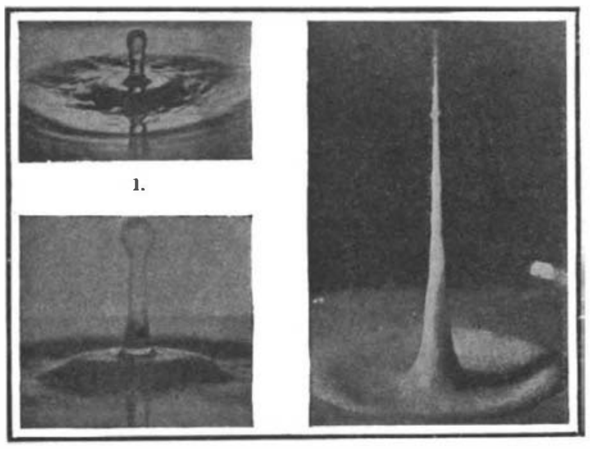
THE LIFE OF A SPLASH.

BY PERCY COLLINS.

Probably many people have at times watched the splashes caused by rain drops falling upon the smooth surface of a pool or river. Some, too, may have gone so far as to differentiate between the splashes formed by the big drops of a thunder shower and those produced by the smaller drops of a gentle rain. In the former case a conspicuous bubble floats for a moment, and then vanishes; in the latter a crystalline fountain seems to start from a surrounding coronet of lesser jets—though this is in part an illusion, for it is known that in reality the coronet has vanished before the jet appears. The image of the coronet has not had time to fade from the eye ere that of the jet is superposed upon it. Moreover, it may have chanced to the reader to note the different effects, both of sound and of splash, produced by a stone dropped into the water—these differences apparently depending upon the height from which the stone descends, and upon the condition of its surface; i. e., whether it is smooth or rough, wet or dry. But if the reader has at one time or another made such naked-eye observations of splashes, it must be clear to him that while he has seen something, he must also have missed seeing very much more. For a splash, no matter in what way it may be produced, consists in the progress of a multitude of events, compressed within the limits of a few hundredths of a second, but none the less orderly and inevitable, and of which the sequence is in part easy to anticipate and understand, while in part it taxes the highest mathematical powers to elucidate.

Some fifteen years ago, Prof. A. M. Worthington, C.B., F.R.S. (Head Master of the Royal Naval Engineering College, Devonport, England), commenced a systematic study of splashes, and in order fully to appreciate the disturbance of the liquids with which he experimented, and their relations, he invoked the aid of photography. In these days of kinematographs and rapid snap-shot cameras, it might seem an easy matter to follow, by means of photography, even a splashing drop. But if the reader harbors this thought, he has failed to grasp the extraordinary rapidity of the movements which take place. As Prof. Worthington reminds us, the problem of how to photograph a splash is by no means a simple one, for the changes of form that take place are far too rapid to come within reach of any ordinary kinematograph, while the quickest photographic shutter is also much too slow. Thus, it became necessary to have recourse to the far shorter exposure of an electric spark. It was found that the bright spark given by breaking the primary circuit of an induction coil at the surface of mercury was of much too long duration to be useful for the purpose of flash photography; so that the originals of the photographs reproduced on this page (for which we are indebted to the courtesy of Prof. Worthington) were taken by means of a spark the duration



1. 2. 3.

1. Primary column succeeding a drop into running water. 2. Column succeeding a drop into still water. Time, 0.139 second each case. 3. Primary column caused by a rough sphere falling into liquid.

of which was certainly less than three-millionths of a second—a period of time which bears to the whole second about the same proportion as a day to a thousand years.

This flash is obtained by charging two Leyden jars by an electrical machine on their inner coats, one positively and one negatively. Stout wires lead from the outer coats to the dark room (where the splash is to be photographed) and terminate in a spark-gap between magnesium terminals and close over the surface of water contained in a bowl. The inner coats of the Leyden jars being now connected together, the positive and negative charges unite in a dazzling flash, and a simultaneous discharge and flash take place between the two outer coats across the spark-gap in the dark room. This latter is the illuminating spark, by means of which the photographic exposure is to be made. The exact timing of this spark is obviously of the greatest importance. This is effected by means of a falling metal sphere which passes (outside the dark room, of course) between two terminals connected one with the inside of one Leyden jar and one with the inside of the other. These terminals are just too far apart for a spark to jump across till the timing sphere passes between them. But when this occurs the discharge takes place, with the accompanying flash in the dark room. By means of an ingenious arrangement of magnets and springs, for full details of which the reader is referred to Prof. Worthington's work ("A Study of Splashes"), the timing sphere can be made to fall either simultaneously with the drop or sphere destined to cause the splash to be photographed, or slightly earlier or later. In this way it is possible brilliantly to illuminate the splash for one three-millionth part of a second at any desired period of its progress. For example, if a particular stage of the splash is photographed when the timing sphere falls just four feet to the gap between the terminals, then by raising its releasing-lever about two-fifths of an inch, the law of falling bodies insures that the flash will be postponed by just one-thousandth of a second, and the next photograph accordingly reveals a stage just so much later.

From these brief particulars the reader will be able to form an idea of the way in which Prof. Worthington's photographic studies of splashes are obtained. The camera being previously focused and arranged in the dark room, the timing sphere is minutely adjusted and released, and a record of any desired period of the splash is obtained upon the sensitized plate. Yet despite the rapidity of the plates employed, and the brilliancy of the flash, the duration of the illumination is so short that the negatives are always "under-exposed." Hence tedious precautions have to be taken in their development.

We may now glance rapidly at a few of the many interesting facts which have been established by Prof. Worthington's study of splashes. It will probably surprise the reader to learn what a lengthy series of events follows the contact of a small drop of water, falling from a height of about 16 inches, into a mixture of milk and water—the milk being added to render the photographs more intelligible. First, as the drops strikes and penetrates the surface, there arises a crater, which rapidly increases in size until, upon

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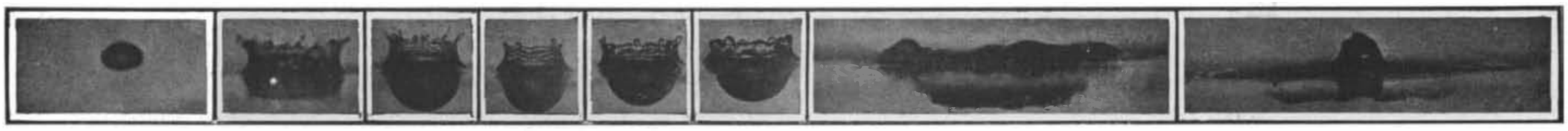
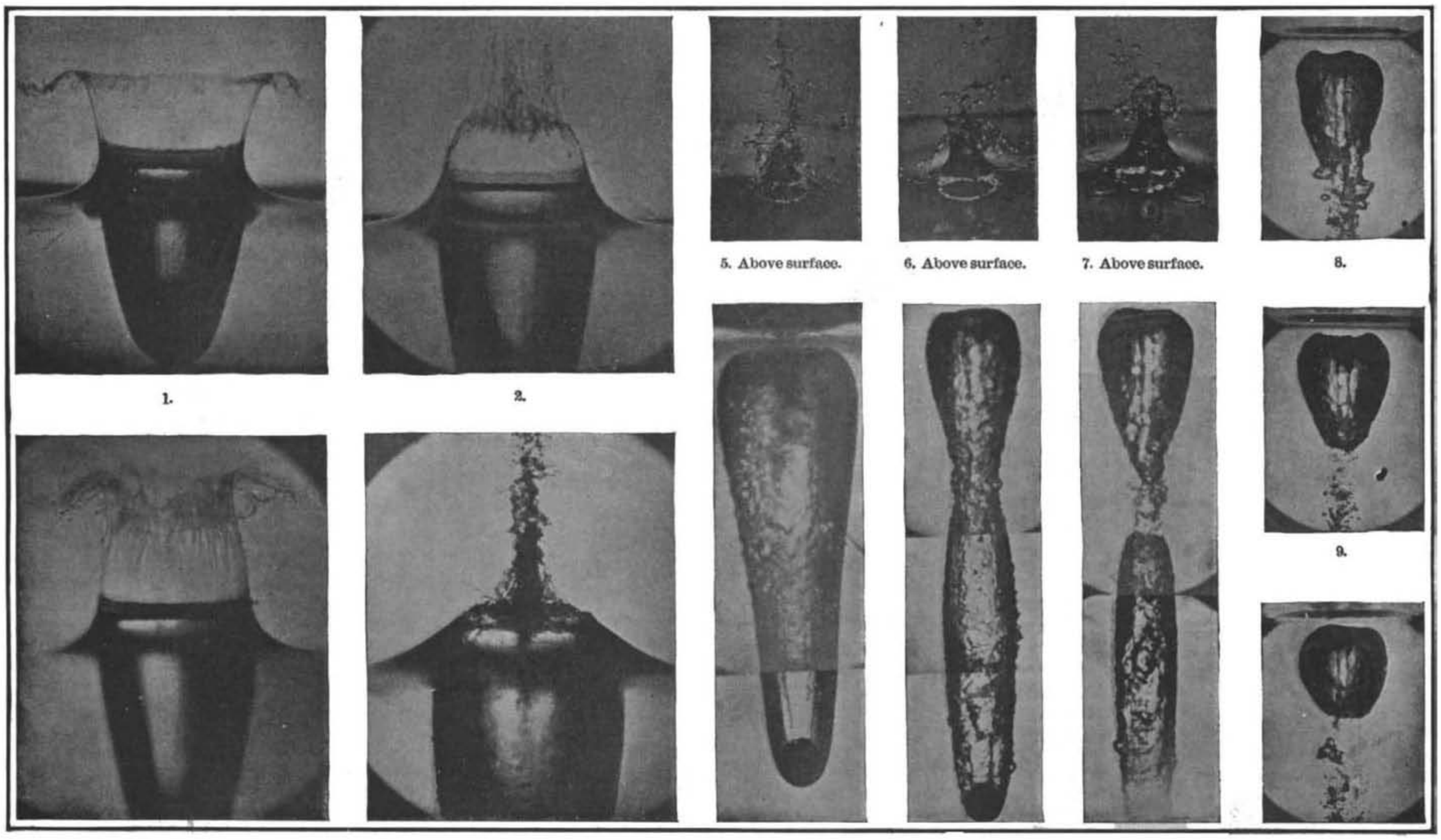


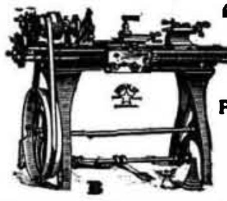
The falling drop. T=0. T=0.012. T=0.016. T=0.023. T=0.039. T=0.055. T=0.070.

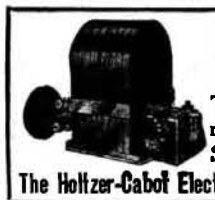
The phenomena of a drop of water falling 40 centimeters into water.



1. 2. 5. Above surface. 6. Above surface. 7. Above surface. 8. 9. 3. 4. 5a. Below surface. 6a. Below surface. 7a. Below surface. 10.

THE VARIOUS STAGES OF A SPLASH PRODUCED BY A ROUGH SPHERE FALLING 680 CENTIMETERS (22.3 FEET) INTO WATER.





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attaining its greatest proportion, its walls begin to thicken, and gradually subside to form a mere ring of lobes on the surface, surrounding a central hollow.

Then comes a rebound, manifested in the rising of a central column which, after attaining its full height and subsiding, is followed by a secondary column ere the series of events which we term "the splash" is complete. Prof. Worthington shows that the separation in the form of a drop of the top of the primary column ere its complete subsidence results in a series of events markedly different from that which ensues when no separation takes place. Moreover, the manifestation of outspreading ripples is affected by the condition of the surface; and in order to secure the most favorable conditions by cleaning the surface, a continous slow stream of fresh water is maintained. The contamination of the surface liquid, by the way, originates in lamp black brought down by each drop; for in order to prevent the drop from adhering to the watch glass in which it rests prior to its fall, it is found necessary carefully to smoke the glass in the flame of a candle. But the atoms of lamp black which adhere to and are brought down with each drop serve to make clear some important points connected with the formation of the splash. They prove by their presence that the interior of the crater is lined by the original liquid which formed the drop, and thus afford useful information as to the nature of its flow. When the primary column commences its ascent, the atoms of lamp black are carried upward at its summit, proving that the liquid of the original drop emerges at the head of the central column. This is confirmed by allowing a drop of milk to fall into pure water, when the photograph shows that the upper part of the column contains nearly all of the milk. This fact may be easily verified by naked-eye observation, as indicated by Prof. Worthington. Let the reader drop from a spoon into a cup of tea or coffee, from a height of fifteen or sixteen inches, a single drop of milk. He will have no difficulty in observing that the column which emerges carries with it the white milk-drop at the top only slightly stained by the liquid into which it has fallen.

Upon increasing the height of the fall of a drop to about 40 inches, a new phenomenon is registered in the photographs. The crater rises to a greater height; but instead of subsiding in the form of a ring, its mouth closes to form a bubble on the surface of the liquid. If the height be not too great, the closing is either incomplete or at any rate only temporary, and the bubble reopens at the top to make way for the column which rises as before from the base, but is now much thicker and hardly so high as before. With a very high fall, however, the bubble becomes too firmly closed to reopen, and its summit is struck from within by the rising column, which becomes entangled in the liquid of the bubble when the latter bursts. Thanks, however, to the influence of surface tension, regularity of form is soon regained, so that the concluding events of a splash after a high fall agree in essentials with those which follow a low fall.

The facts elucidated by experiments with a sphere dropped from varying heights into liquid proved to be of great interest and importance. Prof. Worthington suggests that those who wish fully to grasp the significance of his photographs and deductions should experiment for themselves by dropping marbles from a height of about a foot into a deep bowl of water, the bottom of which should be protected from the possibility of breakage by a few folds of fine copper gauze. A perfectly clean and highly polished marble so dropped will enter the water almost noiselessly with very little disturbance of the surface. In a word, the splash is singularly insignificant. Photo-

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graphic records show that the liquid, instead of being driven away from the surface in the form of a crater (as is the case when a drop or a rough sphere strikes the surface) now rises in a thin, closely-fitting sheath which completely envelops the sphere even before its summit has reached the water level. A comparatively insignificant column constitutes the subsequent splash. Moreover, and as a result of the rapidly closing sheath, practically no air is carried into the water by the smooth sphere. This point, as well as many others of great importance, was shown photographically by means of illumination behind a thin glass vessel with parallel sides—an arrangement which rendered it possible to photograph the splash both above and below the surface of the fluid. Most of the photographs reproduced were taken in this way.

So much for the splash caused by a smooth sphere. If the reader will now fish out the marble with which he is conducting his simple experiments, roughen its surface with sandpaper, and again drop it from a height of a foot or so into the water, he will find that a totally different splash results. There is now a great noise of bubbles, which may be seen rising through the liquid, while a tall jet is seen to be tossed into the air. Photographic records of the surface disturbance closely resemble those which have already been described, caused by the fall of a drop. A crater is formed, and subsides, and a graceful jet rises from its depths, gathers volume from below, and rises ultimately as a tall column whose height may be even greater than that from which the sphere fell. Photographs of the descent of the sphere below the surface show us how this column originates. The sphere as it descends drags with it the surface film of the liquid in the form of a gradually deepening pocket or bag which ultimately forms a long cylindrical hollow. This eventually divides, and the lower part is dragged down by the sphere to the bottom (no matter what the depth), whence it rises to the surface as a bubble. Meanwhile, the upper half of the cylinder rapidly fills up; and this running together of the liquid is responsible for the great velocity of the upward-spurting jet or column.

On increasing the height of the fall of a rough sphere, a higher crater which closes and forms a bubble is obtained, just as when the height of fall of a liquid drop is increased. With a fall of two feet, this bubble is almost immediately destroyed by an upward jet. But if the height of fall be increased to four or five feet, no rebounding jet will be projected into the air, notwithstanding the fact that much air is still carried down by the roughened sphere. To the naked eye, a curious "seething" appearance at the surface is apparent; and Prof. Worthington admits that he was at first disposed to regard this as evidence of the entanglement of the jet with the bubble—an entanglement likely to produce confused motions which could not be profitably studied. However, the persistence with which the seething motion again and again returned when a stone was dropped or thrown into the river, led him to suspect that something required investigation. The remarkable change of procedure revealed in the series of photographs which was subsequently taken will be best described by a word for word quotation from Prof. Worthington's writings. "The earlier figures show the very rapid rise of the crater and its closing as a bubble, much before the entrapped column of air divides. Before the division takes place, the liquid now flowing in from all sides closes over the upper end of the long air tube, separates it from the air outside, and forms a downward jet which shoots down the middle of the air tube in pursuit of the sphere. The first formation of this jet is not easy to observe, because the view is obscured

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by much splashing and turbulent vertical motion resulting apparently from the streams that converge from all sides of the axis of the air tube at its upper end, . . . but (when) the turbulence has cleared away from the upper part, and from this stage onward the jet is well seen in all the figures, and it persists long after the segmentation of the air column has taken place. The reader must not suppose that this jet is a mere falling of the water under the action of gravity, for the rapidity with which it advances is far greater than could be accounted for in this way. . . . The great initial momentum of the sphere causes it to continue in rapid motion after the bubble has closed, thus the sphere acts as a sort of piston, which by increasing the length of the air tube diminishes the pressure in it and so sucks in the bubble, which is driven down by the greater atmospheric pressure above. The converging horizontal inflow near the mouth of the air tube cannot, of course, produce the downward-directed jet without an equal and opposite generation of momentum upward; but this is now expended, not in producing a similar upward jet, but in balancing the excess of atmospheric pressure. The reaction, in fact, to the projection of the jet downward is the force which holds up and slowly raises the roof of the long air shaft." The rising of the roof is well shown in some of the accompanying photographs.

Thus, as Prof. Worthington points out, the formation of a downward jet is not, in a sense, a new phenomenon, but one which, having existed unnoticed before, is now rendered visible by reason of its being produced in air instead of water. An increase in the height of fall to 22½ feet was found to produce but little change in the phenomena coincident to the resulting splash.

As an illustration of the possible application of knowledge gained from a study of splashes in an unexpected quarter, Prof. Worthington draws attention to the fact that photographs of the splash of a projectile on striking the steel armor plate of a battleship bear a close resemblance to photographs of splashes caused by a sphere falling into liquid. There is the same slight upheaval of the neighboring surface, the same crater, with the same curled lip, leading to the inference that under the immense and suddenly applied pressure the steel has behaved like a liquid. The professor suggests that from a study of the motions set up in a liquid in an analogous case, it may be possible to deduce information about the distribution of internal stress, which may apply also to a solid, and thus lead to improvements in the construction of a plate that is intended to resist penetration.

In conclusion it should be said that the number printed below each photograph here reproduced gives the time in decimal parts of a second which has elapsed since the first instant of contact.

CARNIVOROUS PLANTS OF THE FUTURE.

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edge of the leaf in certain species is seen to curl slowly inward. Now we can imagine that in the very far-away future with which we are dealing the Pinguicula will develop leaves which will hardly be less than five or six feet in length. These lying along the surface of the ground will make a special appeal to grazing animals. Perhaps as with the sundew the allurement will be in the form of some pleasant-tasting secretion which is peculiarly attractive to sheep and goats. We can imagine how these animals on first coming across the plants would start to regale themselves at the prepared feast. The strong sticky substances would take a firm hold of the hairs surrounding the mouth parts of the creatures, and in their endeavor to free themselves the animals would become more entangled. Gradually, too, the sides

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Pencil sharpener, A. Rydquist 942,107
Perforating and binding machines, assembly box for, C. F. McBee 942,180
Permutation lock, G. H. Hamilton 942,553
Phenol and formaldehyde and making the same, condensation product of, L. H. Baekeland 942,700
Phenol and formaldehyde, making insoluble products of, L. H. Baekeland 942,699
Phonic apparatus, T. H. Macdonald 942,089
Phonograph, P. Weber 942,475
Picture mount, movable, H. O. Sauer 942,565
Pile, W. N. Louque 942,653
Pipe and rod threader, H. Gautschi 942,200
Pipe fitting, soil, F. B. Morton 942,339
Pipe or rod carrier, G. Holt 942,446
Pipe, skelp treating apparatus for lapweld, H. W. Hock 942,176
Pipes, air vessel for water supply, K. Romstaedt 942,666
Pipes, lining, J. O. Persons 942,184
Pipes with sand, apparatus for filling metal, C. O. Scholz 942,355
Piston for hot-air engines, F. B. Hubbard .. 942,261
Planter, Trammell & Hammack 942,760
Planter and fertilizer distributer, combined seed, E. P. & J. T. Patterson 942,792
Planter and marker, corn, A. W. Koage 942,394
Planter, see, Fowler & Daly 942,495
Plastic material, machine for forming, G. S. & P. H. A. Balsley 942,238
Plate dishing and flanging machine, C. Gabriel 942,062
Plated metal and making the same, J. Wilder 942,803
Pliers, H. F. Kellemen 942,504
Pliers, W. Cronk 942,549
Plow, J. T. Gantt 942,849
Pole sleeve, C. B. Voynow 942,761
Post. See Fence post.
Post office box, H. O. Haywood 942,203
Power device, W. H. H. Baker 942,534
Power generating apparatus, C. J. Lake 942,873
Press for expressing fluids from solids, F. G. Wiselogel 942,301
Pressure generating and applying apparatus, hydraulic, J. W. Nelson 942,736
Pressure regulator, G. W. Collin 942,546
Printing apparatus, frame structure for blue, R. Herman 942,175
Printing machinery, J. A. J. Hayes, reissue. 13,051
Printing press paper feed mechanism, J. E. Tucker 942,296
Printing press rotary folder, W. H. De Bush 942,136
Printing press, throw-off mechanism for the inking rolls of rotary, L. A. Wheat 942,119
Program holder, detachable leaf, F. E. Sauerwein et al 942,670
Program holder, transparent theater, F. E. Sauerwein et al 942,669
Projectiles, attachment for, C. Davis 942,617
Propelling means, vessel, F. Fanning 942,199
Protractor and level, N. R. Thibert 942,114
Pulling over machine, H. Walther 942,155
Pulverizing machine, E. E. Wann 942,424
Pump, C. F. Preslar 942,245
Pump mechanism, M. B. Van Ness 942,297
Punch and shear, C. Peterson 942,209
Punching machine, hand, H. Siegrist 942,291
Punching machine, multiple, C. E. Macbeth. 942,272
Puzzle, W. F. Bartsch 942,536
Quoin, E. J. Casey 942,543
Rack, McGregor & Rudland 942,580
Radiators, pressing device for push nipple, H. L. E. Peterson 942,410
Rail clamp, D. S. Wert 942,427
Rail controlling device, switch, W. F. Doner 942,313
Rail joint, M. Barschall 942,127
Rail joint, W. E. Ransom 942,411
Rail joint, W. P. Perkins 942,662
Railway block signaling system, J. Gaszper. 942,255
Railway carriage doors, appliance for automatically and otherwise locking and unlocking, Andrews & Bickerton 942,125
Railway crossing, I. O. Stant 942,358
Railway crossing, W. C. Peters 942,740
Railway gate, E. L. Kishpaugh 942,783
Railway rail spike and chair, J. T. Nulty .. 942,658
Railway signaling system, automatic, G. H. Sloane 942,468
Railway spike, R. L. Smith 942,668
Railway switch, J. F. Ober 942,458
Railway switch, automatic, Rexach y Torres & Pena y Martinez 942,600
Railway tie, H. C. Krepps 942,650
Railway tie, H. H. Ranje 942,745
Railway tie, metal reinforced, J. F. Lahart. 942,267, 942,268
Railway tie, self-adjusting steel, A. J. Schneider 942,754
Railway ties, etc., composition for, J. Kirkham 942,505
Railway track safety block, L. F. Learman. 942,835
Railways, catenary suspension system for the trolley wires of electric, K. von Kando 942,143
Razor case, W. L. Clark 942.484
Reamer, adjustable, R. W. Bailey 942,533
Receptacle closure, fluid, A. & T. A. De Vilbiss, reissue 13,049
Reclining chair, J. Flindall 942,818
Rectal apparatus, J. P. Sanborn 942,590
Record tablet, G. A. Eliason 942,627
Refrigerating apparatus, J. Heinrich, 942,445, 942,499
Refrigerating machine, R. N. Dyer 942,367
Refrigerating package, A. W. Folsom 942,318
Registering device, R. Hunter, reissue 13,052
Relay, S. D. Field 942,815
Rivet feeding device, J. E. Peters 942,864
Riveting machine, C. Greiner 942,637
Road working machine, M. A. Popkess 942,866
Roasting pan, P. Scott, reissue 13,054
Rock elimination, apparatus for waste, H. L. Kramer 942,083
Rolling mill transfer table. C. L. Huston .. 942,644
Roof ventilator, W. W. Birnstock 942,707
Roofing package, F. C. Overbury 942,660
Rotary engine, H. Roux 942,413
Rotary engine, W. W. Wheeler 942,476
Rotary motor and pump, J. R. Kinney 942,080
Rotary steam engine, J. W. Johnson 942,205
Rotary steam engine, W. E. Minue 942,275
Rule, Jewell & Westcott 942,327
Rule, W. L. Neeld 942,583
Running gear, A. T. Newell 942,182
Sand and slime separator and classifier, C. Allen 942,697
Sanitary ware, J. J. Cosgrove 942,547
Sapphires and other precious stones, machine for cupping, J. L. Wennstrom 942,425
Sash holder and lock, K. F. Deskins 942,716
Sash holding device, O. M. Edwards 942,720
Saw setting machine, A. C. Ambler 942,531
Saw setting tool, J. L'hote 942,573
Saw wheel, band, C. A. Putnam 942,588
Scaffold, S. Pichler 942,347
Scale, ice box and refrigerator, D. G. & A. H. Sansbury 942,286
Scarf pin safety attachment, F. S. Reynolds 942,517
Screens, fly attachment for, E. White 942,120
Screw cutting machine, R. C. Nugent 942,791
Screw driver, B. Presson 942,742
Screw driver and tweezers, combined, Bjorn & Cashmore 942.373
Screw driver, spiral, J. A. Leland 942,571
Screw, set, A. Levedahl 942,506
Seal and spout for cans and other receptacles, H. A. Truesdale 942,847
Seal, metallic, W. E. Elliott 942,315, 942,316
Seal, snap, E. J. Brooks 942,774
Seal, tag attaching, E. J. Brooks 942,435
Seals, packing and registering, W. E. Elliott 942,317
Sealing box fasteners, tool for, R. Schleicher 942,673
Seam dampening machine, turn down collar, W. A. Zeidler 942,233
Seeder, C. W. Stark 942,868
Sewing machine, W. A. Mack 942,090
Sewing machine gage, N. Friedman 942,496
Sewing machine holder, combination, Walker & Parrish 942,802
Shade bracket, window, C. W. Brown 942,775
Shade holder, W. A. Painter 942,738
Shaft, pneumatically operated, P. J. Grebel. 942,065
Sharpener for lawn mowers, E. Merritt 942,578
Sharpener, knife, M. L. Hawks 942,172
Sharpening device, razor, J. J. Meehan 942,731
Shaving appliance case, W. L. Clark 942,483

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