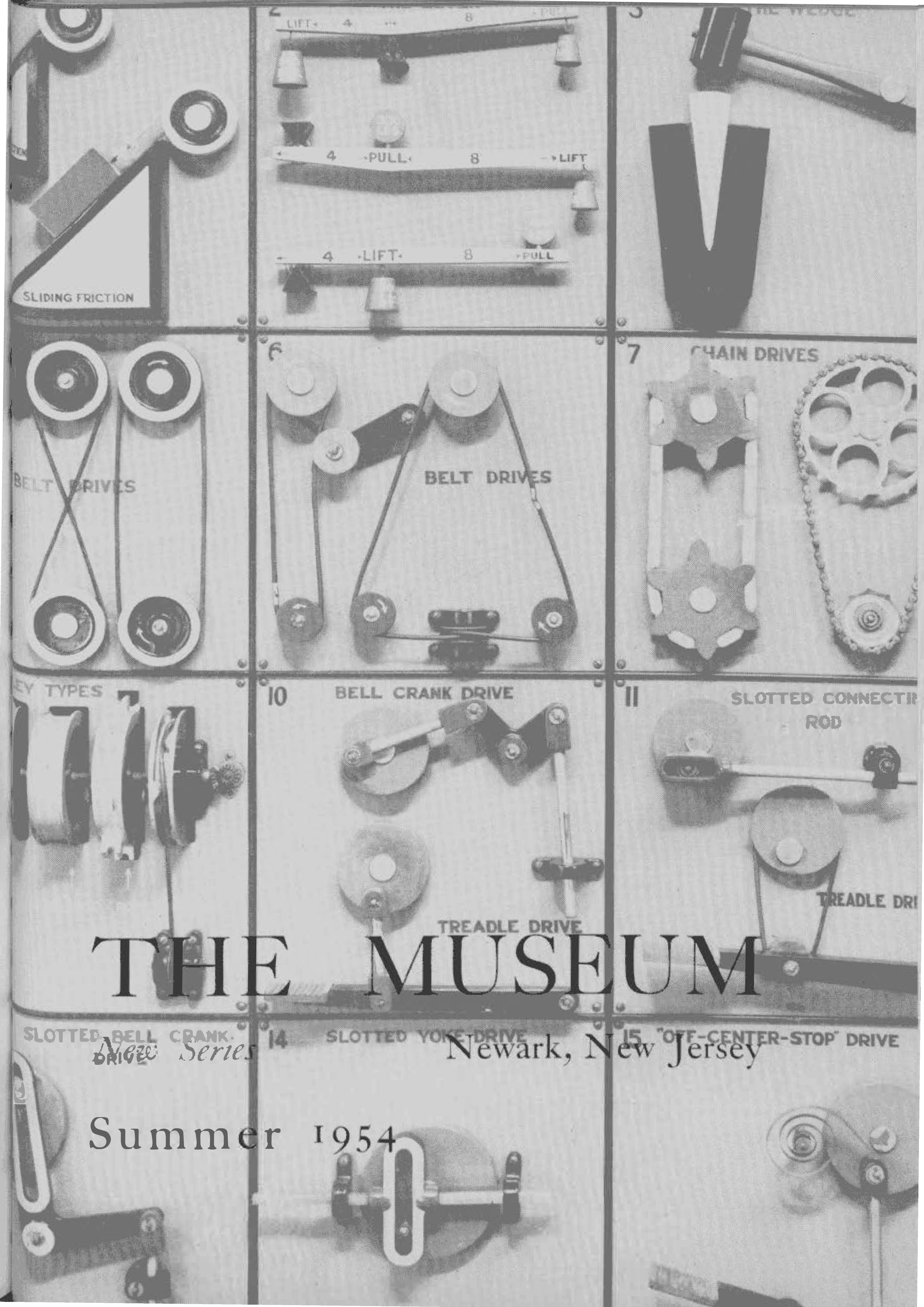

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NOTE

John Cotton Dana's concept that a museum "should reflect our industries, be stimulating and helpful to our workers; promote an interest in the products of our shops," and his desire "to make adult Americans more pleased and proud of the mechanical achievements of their countrymen; and to arouse in the young an interest to do all kinds of things from the driving of a nail with a hammer to the construction of a motor car," lead him in 1926 to inquire about an exhibition of mechanical models on display in a New York department store. This exhibition, the life work of a New Jersey inventor, Mr. William M. Clark, consisted of panels on which were mounted one hundred-sixty working models, showing the fundamentals of mechanical movement, beginning with the first principles and covering the development, both practical and experimental, in a more or less natural sequence. What Mr. Clark had succeeded in doing was to condense into simple, compact, and easily operated models all the movements or combinations of movements used in mechanics. The first set he designed and constructed went to the New York Museum of Science and Industry, known at that time, in 1929, as The Museum of Peaceful Arts. This set now belongs to the Museum of Science, Boston. After Mr. Dana's death in 1929, Mr. Louis Bamberger ordered a second set of this "dictionary of mechanical movements" for the Newark Museum.

The models have been on exhibition continuously since 1930 with a few interruptions when they were lent to Mr. Clark for the Chicago World's Fairs of 1933 and 1934, and to the Massachusetts Institute of Technology in 1937 for display during the Annual Meeting of the Society for the Promotion of Engineering Education.

The thousands of people who have viewed this exhibition in the past twenty-four years have found considerable enjoyment in studying the mechanical operations presented effectively in it. It gives us pleasure to bring to our members and friends the following history of the principles of mechanical movements prepared by Kenneth Gosner of our Science Department Staff.

KATHERINE COFFEY, *Director*

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MECHANICAL MODELS

A Collection of The Newark Museum

By KENNETH L. GOSNER

For most of us, who are not trained engineers, the insides of a clock, a typewriter, or the mysteries hidden under the hood of a modern automobile present a picture of baffling complexity and even confusion. It is usually enough if the machine does what it is intended to, if its parts move according to the engineer's design. When this does not occur, when the machine fails, we are lost, frustrated, and usually annoyed. Then we anxiously call for the mechanic. Constantly we are confronted by the latest marvels of a highly technological era. If we are not familiar with the machines themselves we are at least familiar with their resulting product. Surprising then that an understanding of the principles of mechanical movements, which are so important to our civilization, has become more and more the province of engineers and mechanics alone.

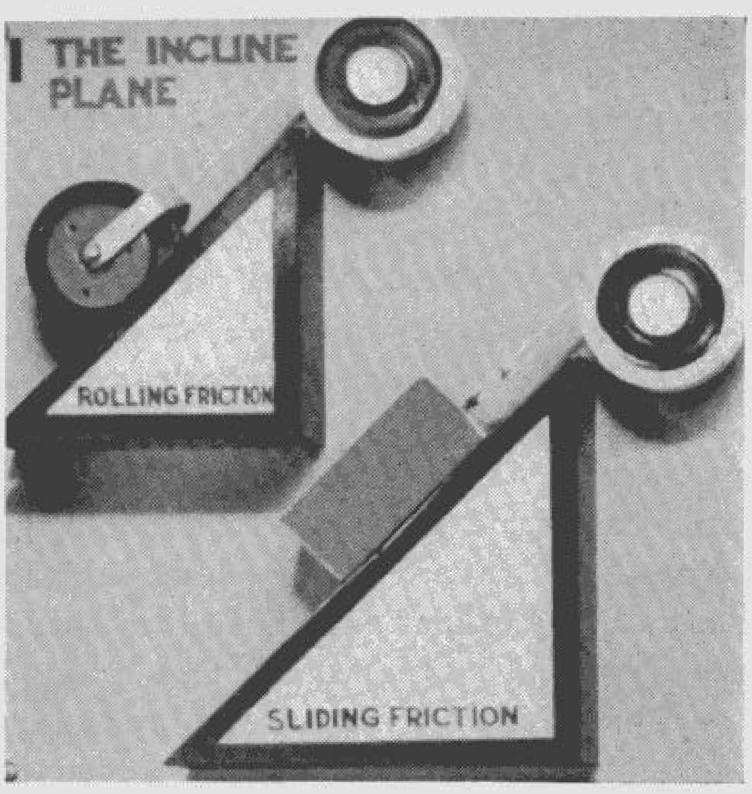
The mechanical fittings of our culture result from the application of but a few principles, a few compared to the multitude of devices based on them. The inclined plane, lever, wedge, and pulley, together with the wheel and axle and the screw, are often called the six elements of mechanical movement—the six "simple machines." They provide the basis for mechanical invention. Nor are these the exclusive property of mankind or the product of his imagination alone. Simple machines may be found in the animal kingdom and elsewhere in nature. To take a familiar example the mosquito. The mosquito flies and walks by manipulating the levers that make up her leg and wing attachments. The same mosquito, if she has the opportunity, makes effective use of a wedge when she punctures the skin in search of nourishment. Birds, which have been flying since Jurassic times or more than a hundred million years before man's labored efforts to get off the ground were successful, raise their wings by an arrangement of bone, muscle, and tendon which approximates the pulley in principle. When animals first climbed up out of the sea to conquer land habitats they very probably used the principle of the inclined plane.

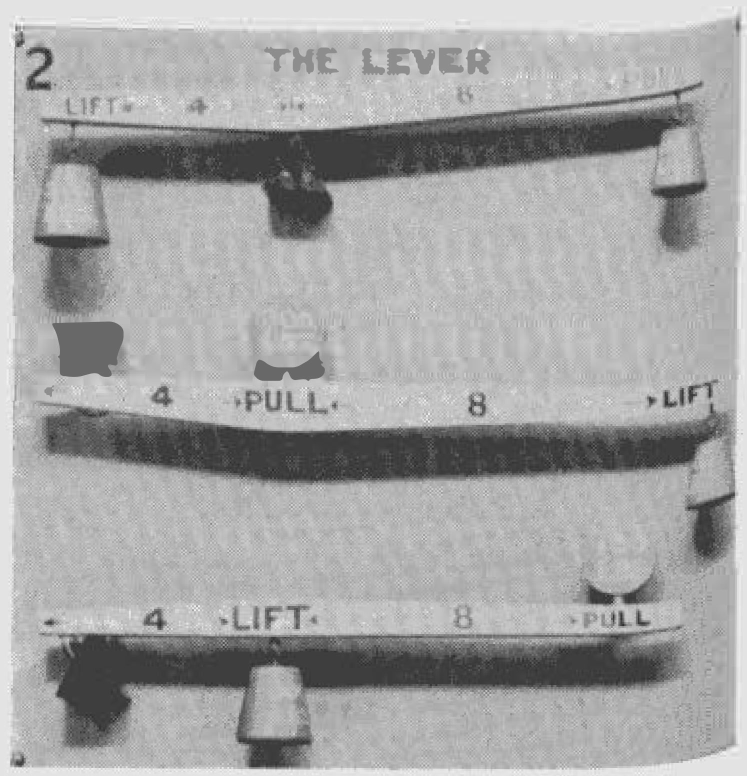
Elementary machines, as well as fundamental mechanical movements and such complex pieces of machinery as an automobile engine, are shown in an operating exhibit of Mechanical Models in the Museum. One hundred-sixty movements and inventions are shown, and the photographs illustrating this text are taken from the exhibition. Historically the exhibit may be said to cover the period from man's earliest use of tools other than his own hands to the present age of internal combustion engines, turbines, and steam locomotives.

Examples of the use of the inclined plane, lever, and wedge are found abundantly in nature, and these few simple machines were employed by early man in the fashioning of tools. The use of mechanical devices goes back far beyond the limits of recorded history. The inclined plane and the lever were perhaps the first mechanical elements put to work. The principle of the wedge, which is really a form of the inclined plane, came into use when early human hunters and fishermen sharpened sticks to make the first spears. Later the wedge formed the basis of the sharp cutting edges of stone knives and projectile points.

As long as man followed a meager existence gathering the roots, nuts, berries, and fruits that grew around him, or was satisfied to fill out this vegetable diet with game and fish, his technology remained a relatively simple one. Later he began to perfect the techniques of agriculture, growing his own crops of corn and rice and domesticating dogs, pigs, and horses. But man's progress in improving the tools with which he worked went slowly. The discovery of fire gave him a means of improving the qualities of some of the tools that he already had and of using previously untried raw materials in perfecting new implements. The use of metals began with the smelting of simple ores and the pounding into useful shapes of native metals. The inclined plane, lever, and wedge, unassisted by other mechanical elements, continued to serve as the foundation of applied mechanics even into the period of ancient civilization. With simple mechanisms the Egyptian architects of 5000 years ago built the pyramids. During most of this long struggle, muscle power provided the force to accomplish human undertakings. Manpower alone raised tons of granite and limestone blocks into the fantastic pyramids of ancient Egypt, hundreds of thousands of men laboring for twenty years or more to accomplish this.

Just when and by whom the principle of the wheel, screw, and pulley was added to man's store of mechanical knowledge we do not know. It is possible that these advances took place during the Bronze Age. Although wheeled toys have been found among the artifacts of ancient Mexico, the Indian civilizations of the New World, like the builders of the early Egyptian dynasties, depended mainly on the first three of the six simple machines. The wheel may have evolved through the use of rollers made of rough logs employed to move blocks of stone. By cutting off thin sections of a log and connecting two of them with an axle, wheeled vehicles could have been brought into existence. Wheeled chariots were in use in Babylonia at least as early as 3000 B. C. The origin of the screw is just as obscure as that of the wheel. Mechanically, a screw is a cylinder with an inclined plane wound spirally around it; a triangular piece of paper





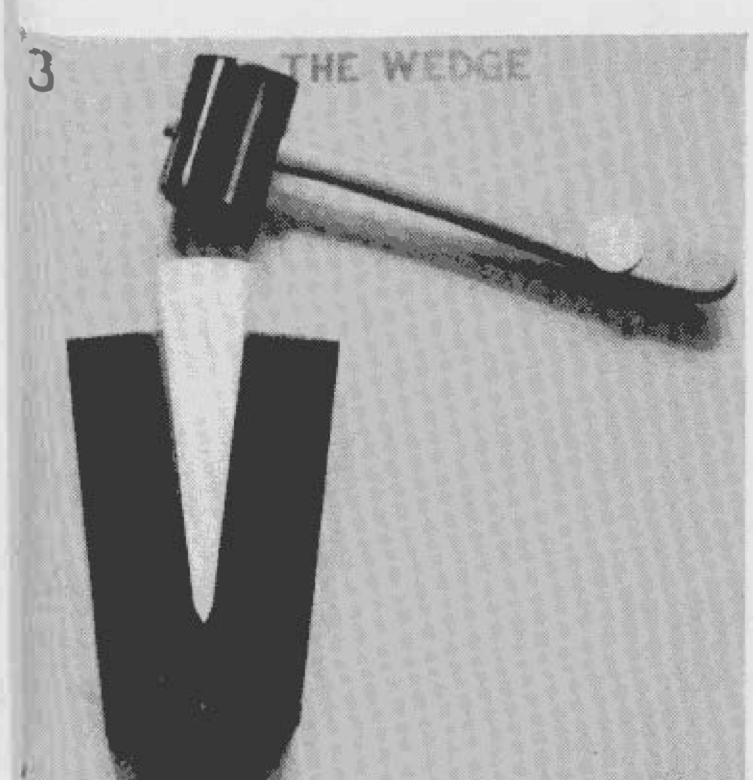
ound about a pencil illustrates the principle volved. However man hit on this device, olive resses using the screw were in operation several enturies before the beginning of the Christian ra and the pulley had also been invented by hat time.

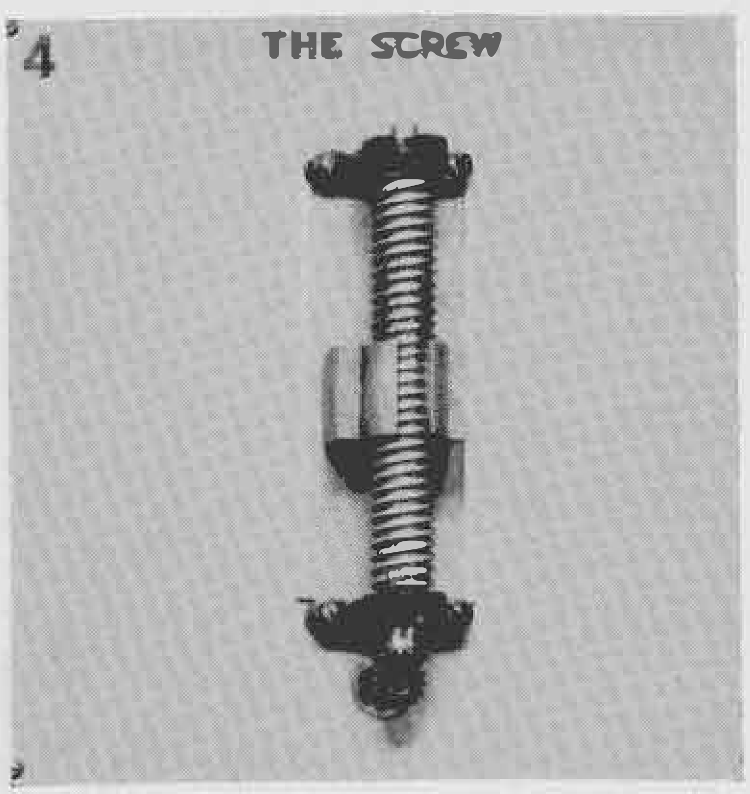
The simplest mechanisms provided the basis for uman invention during the early period of corded history. While camels, horses, and attle were broken to the task of carrying burdens n neolithic time, they were not used to provide he force to operate machinery. The talents of he engineer were mainly directed towards the onstruction of roads, bridges, public buildings, nd the implements of warfare. Probably through ack of a necessity for more elaborate mechanisms, vention lagged. Machinery depending on the genuity and skill of men using established prin- ples continued to be fairly simple in design. his condition remained in effect during the time f the civilizations of Egypt, Greece, and Rome.

No serious attempt to accumulate knowledge f mechanical movements into an organized body f facts was made until the time of Archimedes f Syracuse (287-212 B. C.) who is credited with unding a science of mechanics through his udies on levers. In Alexandria, during Hellen- tic times, a mathematician and mechanic named eron put down all that was known to him of echanical matters in a work called "Book on the Raising of Weights." But the emphasis in Greek civilization was not on technology, and an interest in mechanics was considered somewhat beneath the dignity of the philosopher and thinker.

Thus, as a science, mechanics languished for a very long time. With the beginning of the Renaissance, the situation began to change. Western civilization, after a long period of comparative quiescence, had again picked up momentum. Larger populations and increased trade made new demands on the technology of nations. Into this setting came Leonardo da Vinci. While he is remembered for his accomplishments in art, he made important contributions to mechanics and invention as well. Many of da Vinci's sketches and ideas anticipated inventions hundreds of years in advance of their accomplishment. He also gave his attention to the study of mechanical movements and devices whose usefulness was not limited to any particular machine but which might find a place in various mechanisms suited to a variety of tasks. This attention to fundamentals, as preserved in da Vinci's notebooks and manuscripts, served as a source of ideas and inspiration for other inventors as the Renaissance spread from Italy to Germany and France.

Some of da Vinci's more ambitious schemes were never realized, partly because of a lack of



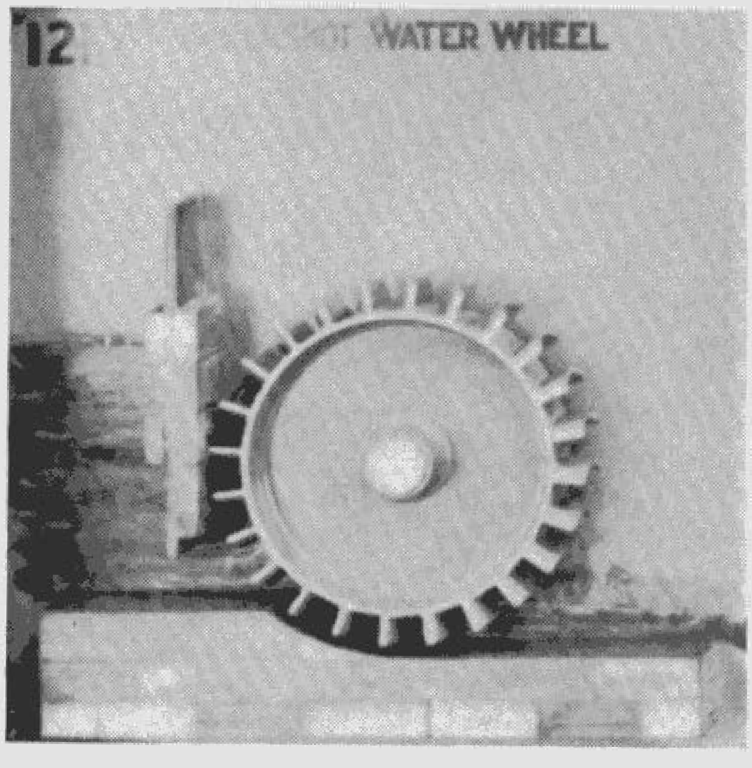


suitable sources of power to set his machines in motion. This search for newer and better "prime movers," or power sources, marks the history of man's technological progress and particularly his development of industry. As early as the fifth century A. D., the power in flowing rivers was put to work; windmills made their appearance five hundred years later. Da Vinci's invention of the turret windmill was, perhaps, the only fundamental improvement in the operation of prime movers until the development of the steam engine. His innovation permitted the top of the mill to be turned in order to take advantage of the wind from whatever quarter it might come.

The introduction of water supply systems for large cities, such as Toledo in Spain, as early as 1526, or just after the Spanish conquest of Mexico, sharpened the need for more efficient sources of power. Pumps were needed for this operation, and more efficient pumps were also in demand for the work of keeping deep mines clear of water. The pumps then used had not undergone much change since the time of the ancient Romans. Thus, necessity was truly "the mother of invention;" not only was there a need for better pumps but for better power sources to drive them. The improvement in pump design, notably in the invention of the vacuum pump, answered an immediate need and also laid the groundwork for the development of the steam engine.

The steam engine was a long time being born. Heron, writing way back at the beginning of the Christian era, described a steam engine called the *eolopile;* although this device remained little more than a scientific curiosity, it may properly be regarded as the ancestor of both the steam engine and the steam turbine. The names of a number of scientists, Galileo among them, are linked to studies on the vacuum and steam which provided a background in pure science for the invention which was to revolutionize technology. In 1663 the Earl of Worcester developed a workable steam engine, and within forty years steam engines were in use powering mine pumps. Seventy years later James Watt made the critical improvements in steam engines which provided man with a reliable, easily controlled source of motive power, and by the beginning of the nineteenth century, the "Age of Steam" had begun with steam locomotives, steam boats, and steam engines driving machinery in industry.

To continue the story of the development of the principal prime movers that powered the technological revolution which has taken place in the past fifty to one hundred years, it is necessary to mention the steam turbine. A primary advantage of the turbine is its direct development of a high speed motion admirably suited to the needs of electric generators and the power plants of sea-going ships. These applications came in the last decade of the nineteenth century, which also



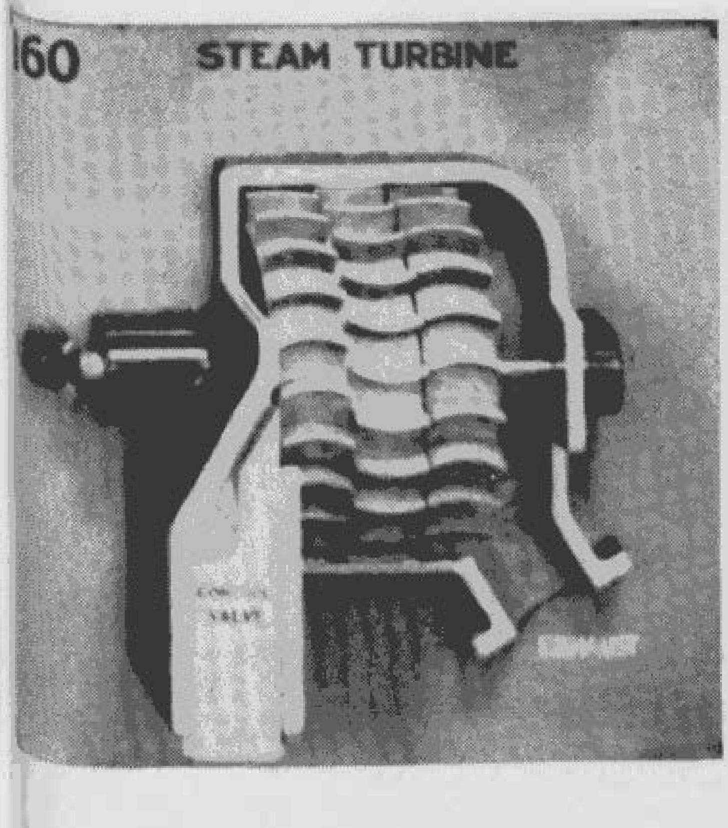
w the invention of electric dynamos and the ctric motor.

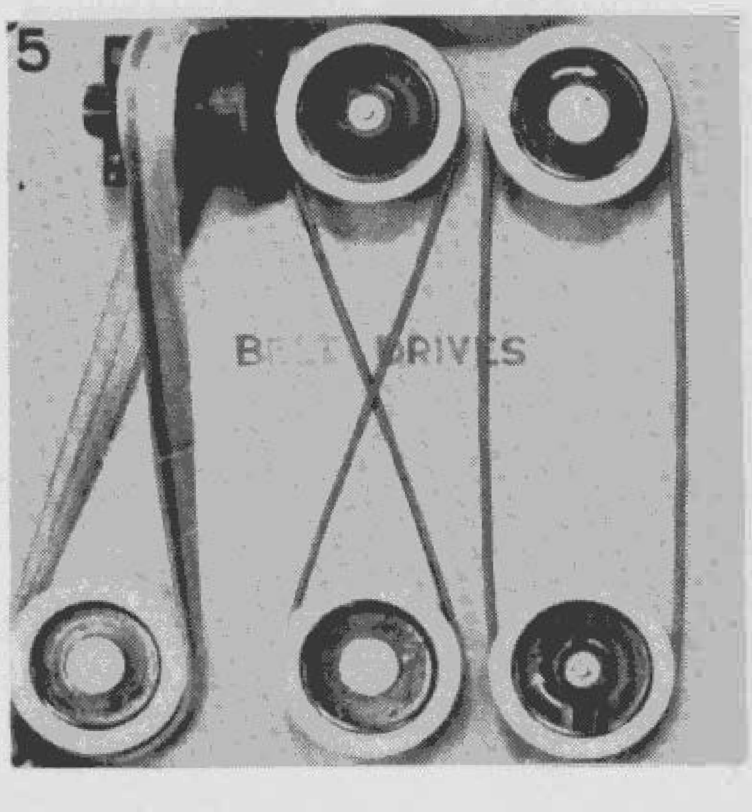
The steam engine and the turbine provided avy sources of power useful for stationary ants and for driving large pieces of machinery h as locomotives and ships. They did not swer the need for light-weight power plants ich might be used to drive a "flying machine" a "horseless carriage."

The idea of "putting the furnace into the inder"—that is, of building an internal com- stion engine—was suggested as far back as 80. At that time the Dutch physicist, Huygens, posed using the explosion of gunpowder as a ans of generating motive power. Gunpowder ved too difficult to control. A mixture of pentine and air gave better results, but it was drogen and air, mixed and exploded in the nder of an engine, that permitted W. Cecil to lve a workable internal combustion engine. at was in 1820 in England. From this begin- g came the gasoline engine which helped ful- the dream of human flight. The automobile, k, and piston-type aircraft engines of today the offspring of this vital development. With w sources of power available and being con- ntly improved, technology had a clear field for most unlimited expansion.

Along with the development of better power rces came improvements in materials, notably through advances in metallurgy and chemistry. Theoretical mechanics and mathematics established a scientific foundation for the engineering of mechanisms which must meet extraordinary requirements in order to function smoothly and efficiently. Included in this general forward movement of mechanical invention is the elaboration of a wide variety of ingenious mechanical movements. Nearly half of the models in the Museum's exhibition are fundamental types of movements which find a use in more than one type of instrument and mechanism. In the physical sciences, a machine is defined as "a device to change the magnitude, direction, or velocity of a force." Let us see what this means in terms of the mechanical movements exhibited.

The force, mentioned in the definition of a machine, comes from turbines, steam engines, electric motors, or any other source of motive power. The problem is to put the whirling drive shaft and the reciprocating movement of the piston to work. The "work" to be done may be a delicate task like driving a mechanism to tell time—an electric clock. The turbine may be used to propel a 60,000 ton ocean liner; the steam engine may be the driving force behind some huge factory installation. In order to use sources of power for such varied tasks, the power has to be manipulated in diverse ways. For example, the electric clock motor moves three different "hands," and these movements must be very finely coordinated. The





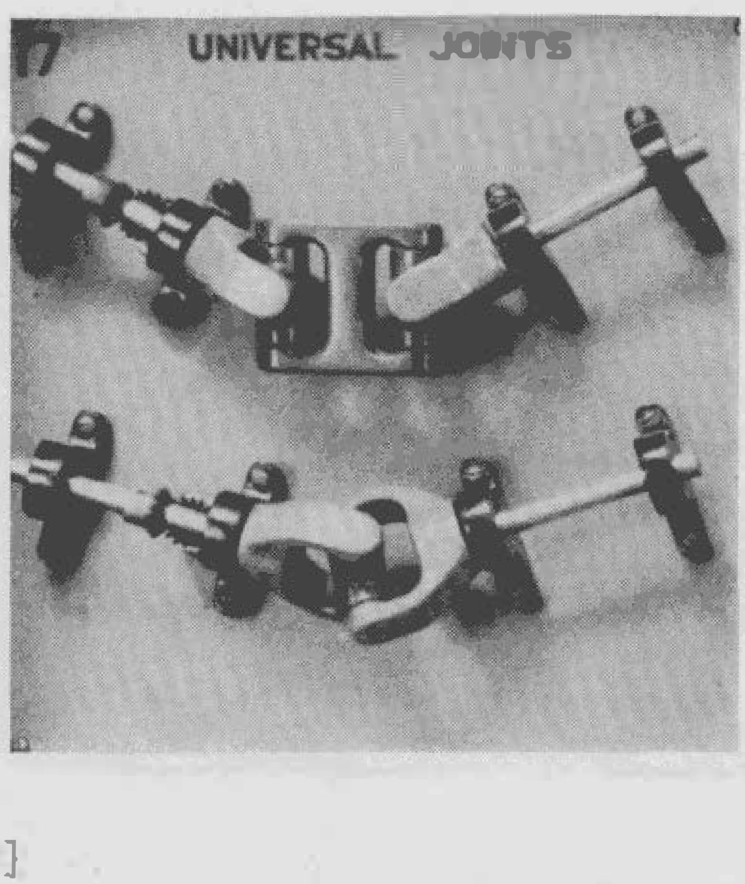
ocean liner must be able to change speed, back up, stop; some arrangement must be made between the whirring turbine and the screw propellers to do these things. The factory machine, automatically pressing out plastic parts or forming boxes or packaging food, incorporates a variety of ingeniously organized movements.

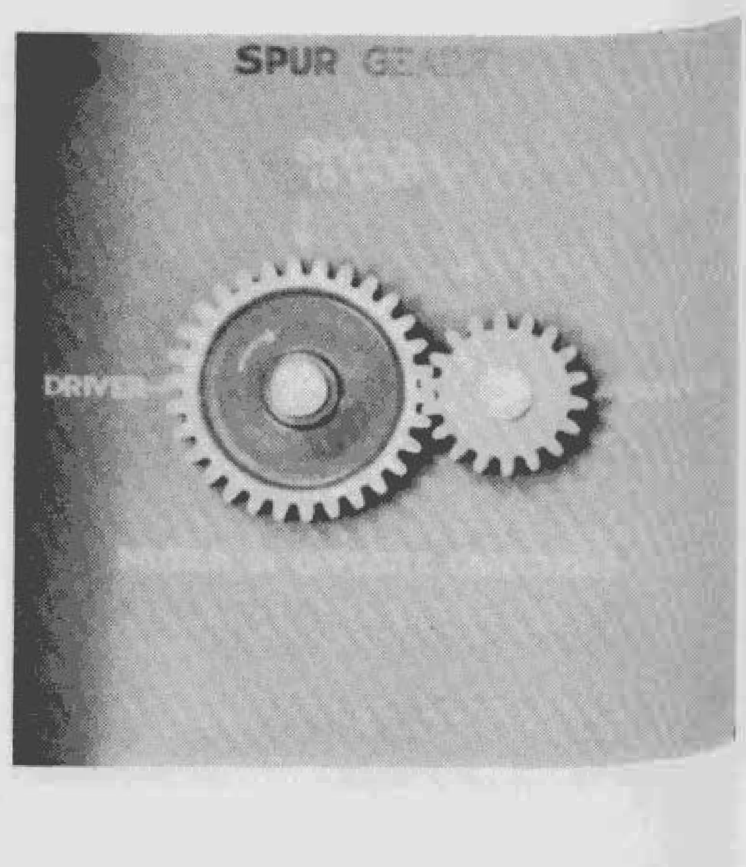
Various devices have been created to transmit power from the prime mover to the machinery which it propels. One of these is the belt drive as shown in the exhibition. We find such drives or devices in a variety of appliances, on the old-fashioned foot treadle sewing machine, for example, and in various power tools in the home workshop. The panel shows three different arrangements of driving belts. The driver and driven wheels in each case are the same size so the speed and power transmitted remain unchanged. The drive on the right is set up so that the wheels, driver and driven, turn in the same direction. By crossing the belt, the driven wheel is made to turn in the opposite direction from the driver as shown in the center illustration. At the left are driver and driven wheels, the axes of which are at right angles to each other.

Another type of drive, the universal joint, provides a means of transmitting motion "around corners," the axis of the driven shaft being at a different angle from the shaft of the driver. When used to carry the power from the motor of an automobile to the rear wheels, this device makes a flexible joint designed to sustain the shocks and bounces of a moving car.

Gears provide an extremely versatile means of manipulating motive power. The first gears, wooden ones, were used in mills before the start of the Christian era, and in today's technology gears exist in a great variety of size, shape, and purpose. The illustration shows a simple form—a pair of spur gears. One of these gears is larger than the other, which means that the two do not turn at the same speed. If the larger gear is the driver, the smaller gear turns faster but exerts less power. Notice also that the driven gear moves in the opposite direction from the driver. Gears may be found in a variety of household appliances—in an egg-beater, for example. In such a drive the large gear, rotated by hand, turns a pair of smaller gears at a much higher speed, and the motion of the mixing blades is at right angles to the motion of the hand. Panel 5 shows a number of different types of gears, including some for transmitting types of variable and eccentric motions.

Pulleys serve as a familiar example of mechanical movements involving change of power. In the illustration two pulleys are shown. The one at the left is a simple one; one pound of pull lifts one pound of weight. At the right, however, two pulley wheels are employed; here, one pound of



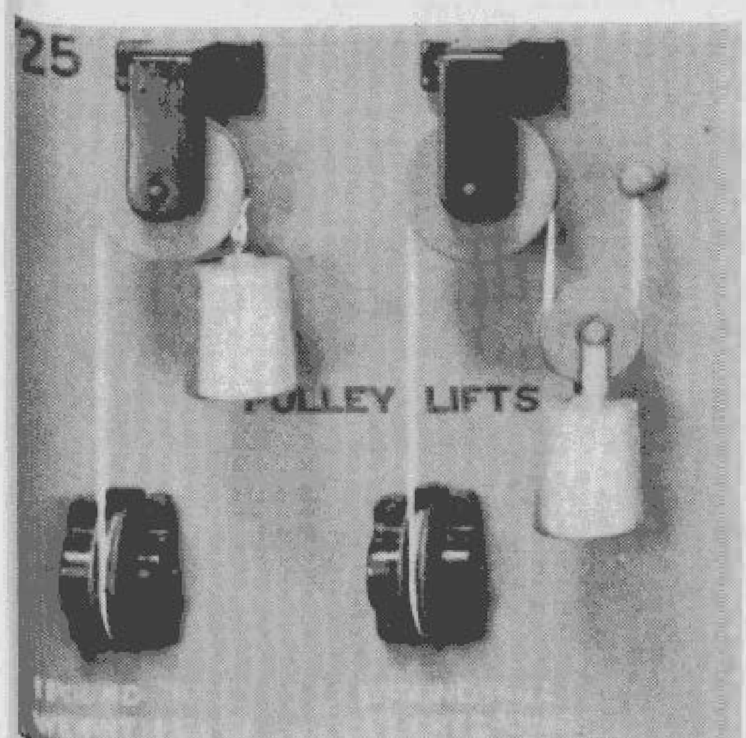


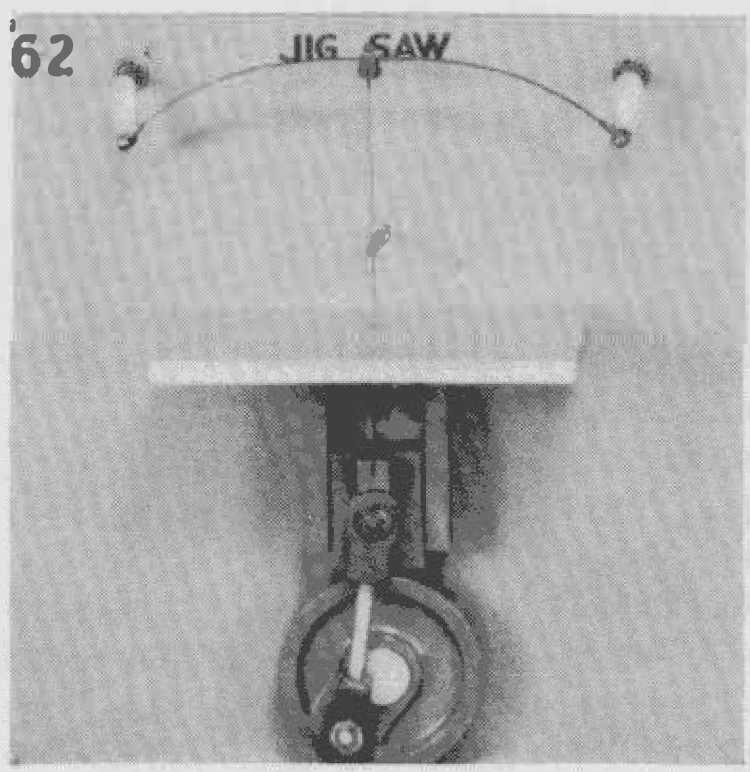
ull raises two pounds of weight. Other pulley fts are shown on the same panel, one of them aving a ratio of one pound of pull to 26 pounds fted. Complex arrangements of pulleys may be een on cranes and derricks and in other installa-ons for handling heavy weights.

In order to put the force of a steam engine to ork, some way must be found to transform the eciprocating—to and fro—motion of the piston to a rotating one. In similar ways the applica-on of motive power often involves changes in nd of movement. The driving rods of a loco-otive transmit the reciprocating motion of the comotive's pistons to the driving wheels, making e latter revolve. This is a type of crank motion. an electric jigsaw the problem is reversed. wer, in this case, comes from the revolving aft of an electric motor. As shown in the cut crank motion is used to effect an up and down vement of the saw blade. A very ancient type device for changing a to and fro movement to a revolving one is found in the bow drill or e-making bow used by primitive people in many rts of the world.

The requirements of such modern machinery an automatic bottling or packaging machine mand a considerable number of movements urately timed to work together. Intermittent d variable movements must be worked into the design of such a mechanism and it may require reciprocating, rotating, and irregular motions of various sorts. Dozens of details of operation, attended to by one machine and perhaps driven or controlled by a single power source, call for a variety of mechanical devices. The panels in this exhibit include cams, stops, ratchets and pawls, jump motions, clutches, eccentric drives, and other mechanisms. The first five panels are primarily devoted to these and the best way to gain some insight into such mysteries is to watch them in action. A list of the motions and devices shown in the exhibition is appended to this article along with illustrations of the full panels. In addition to showing fundamentals, the exhibition also gives cutaway operating views of a number of house-hold and automobile parts together with watch and clock escapements and a variety of power sources, including steam engines and turbines.

Since 1930 when the collection was presented to the Museum by Louis Bamberger, the exhibi-tion of Mechanical Models has provided an un-usual opportunity to see *inside* machinery. Many thousands of visitors have delighted in the clear presentation of mechanical movements in opera-tion. The collection of one hundred and sixty movements, arranged on ten panels and operated by switches under the control of the visitor, was designed and constructed by Will M. Clark.





MECHANICAL MODELS

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2. The lever
3. The wedge
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6. Belt drives
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23. Eccentric drive
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156. Aero radial engine
157. Steam turbine, Peltonwheel type
158. Valve gear
159. Steam engine reversing links
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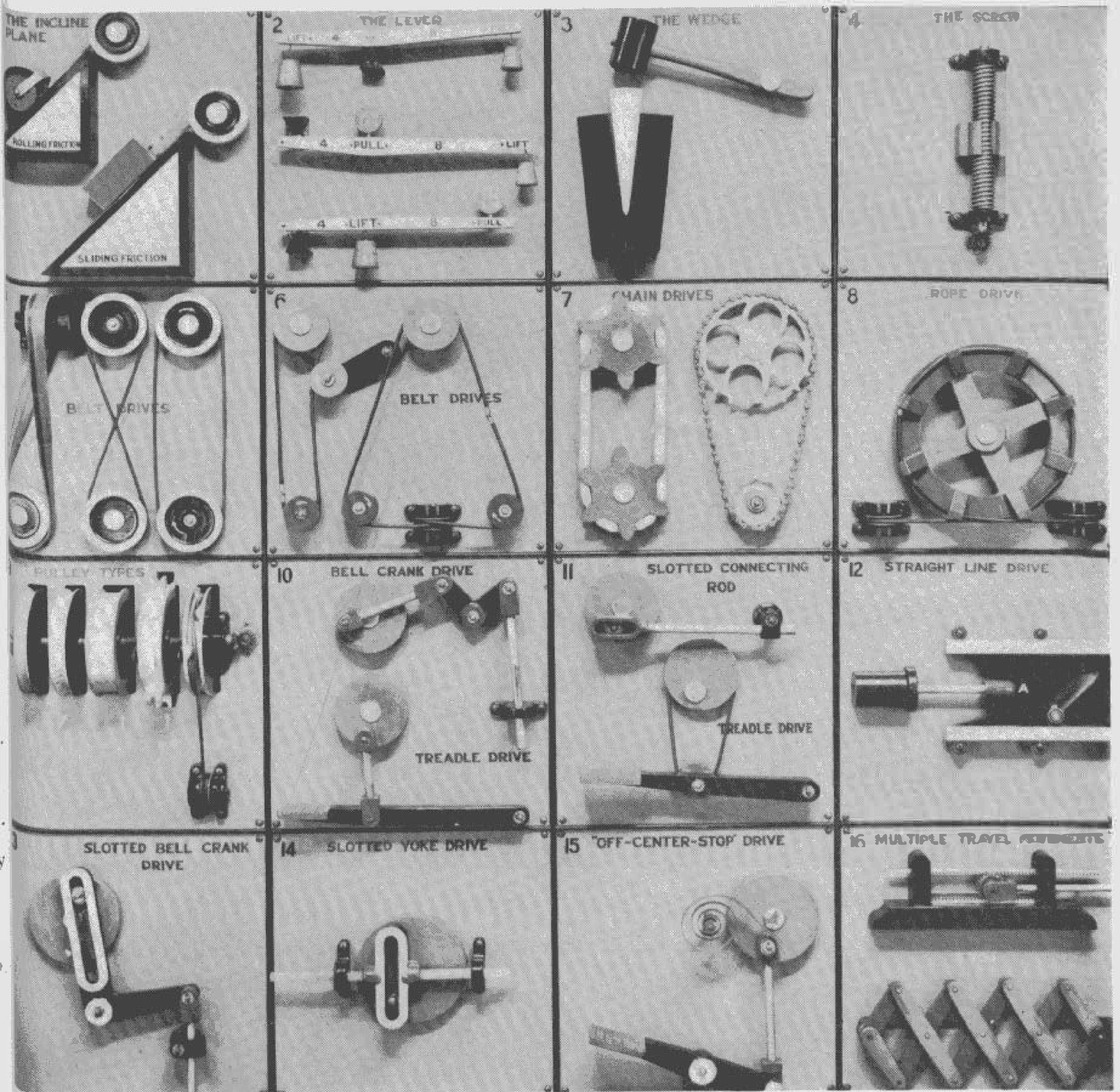
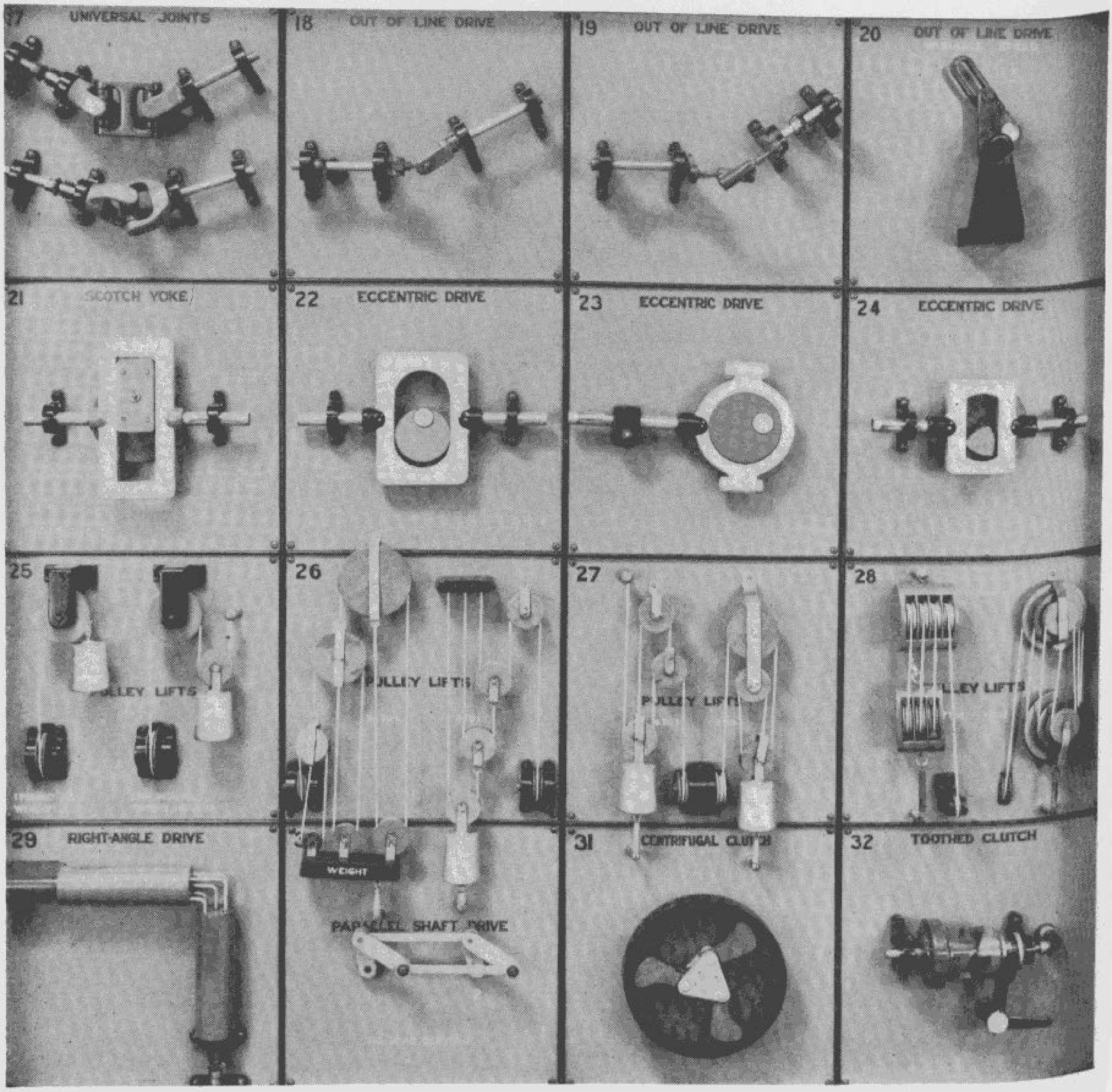
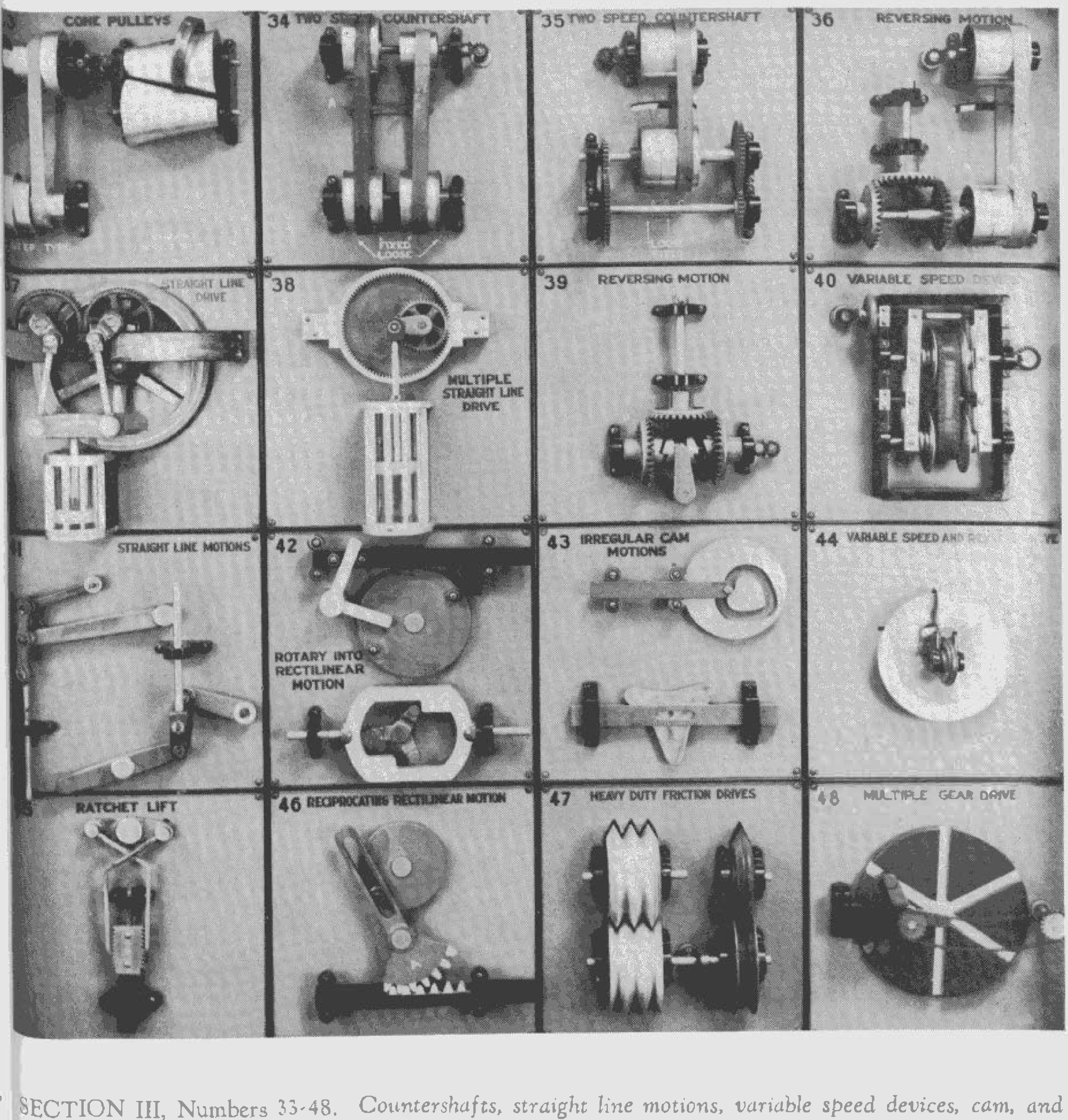
SECTION I, Numbers 1-16. *Four principles of mechanics. Belt, chain, rope, foot treadle, and miscellaneous drives.*

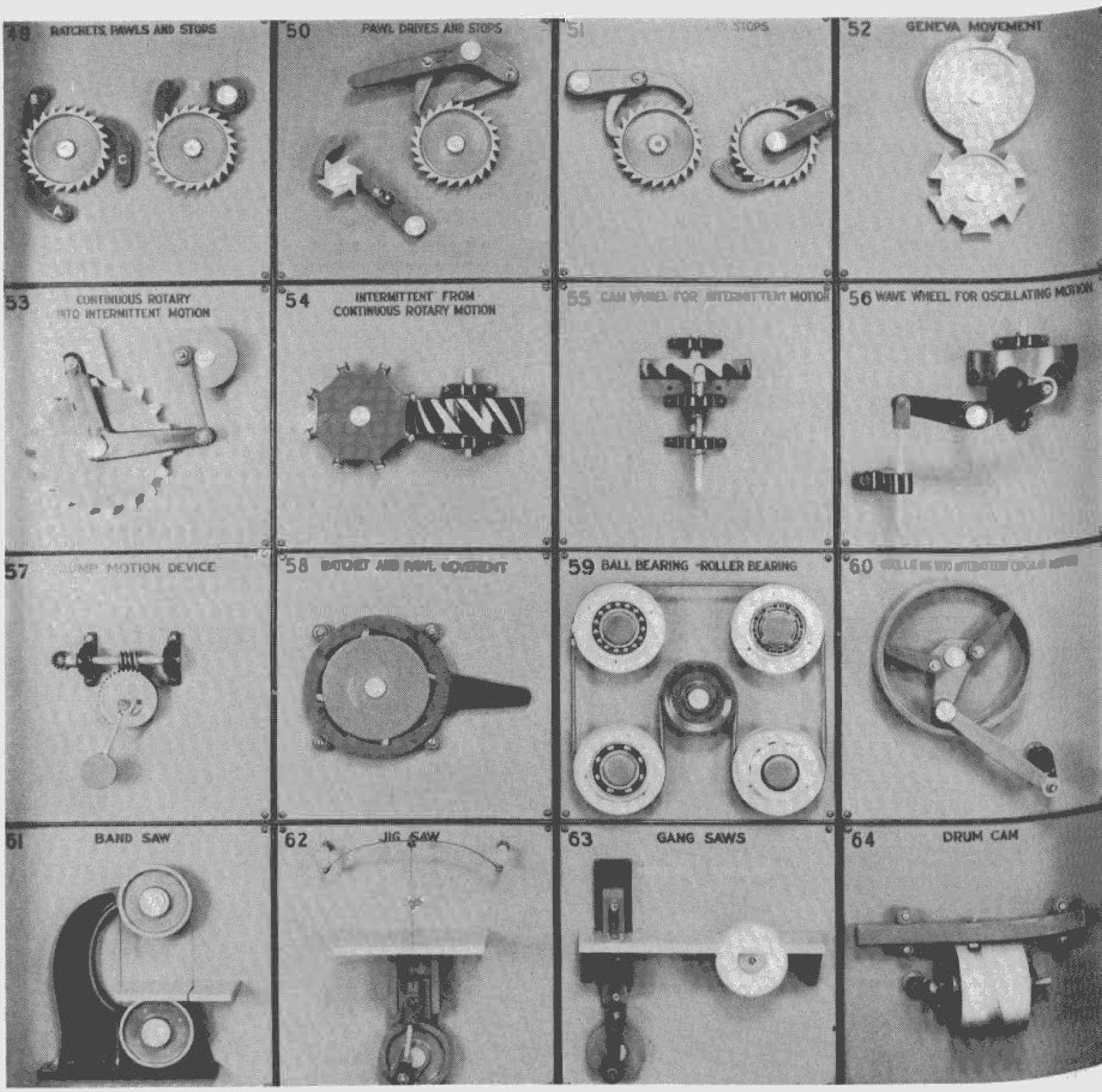




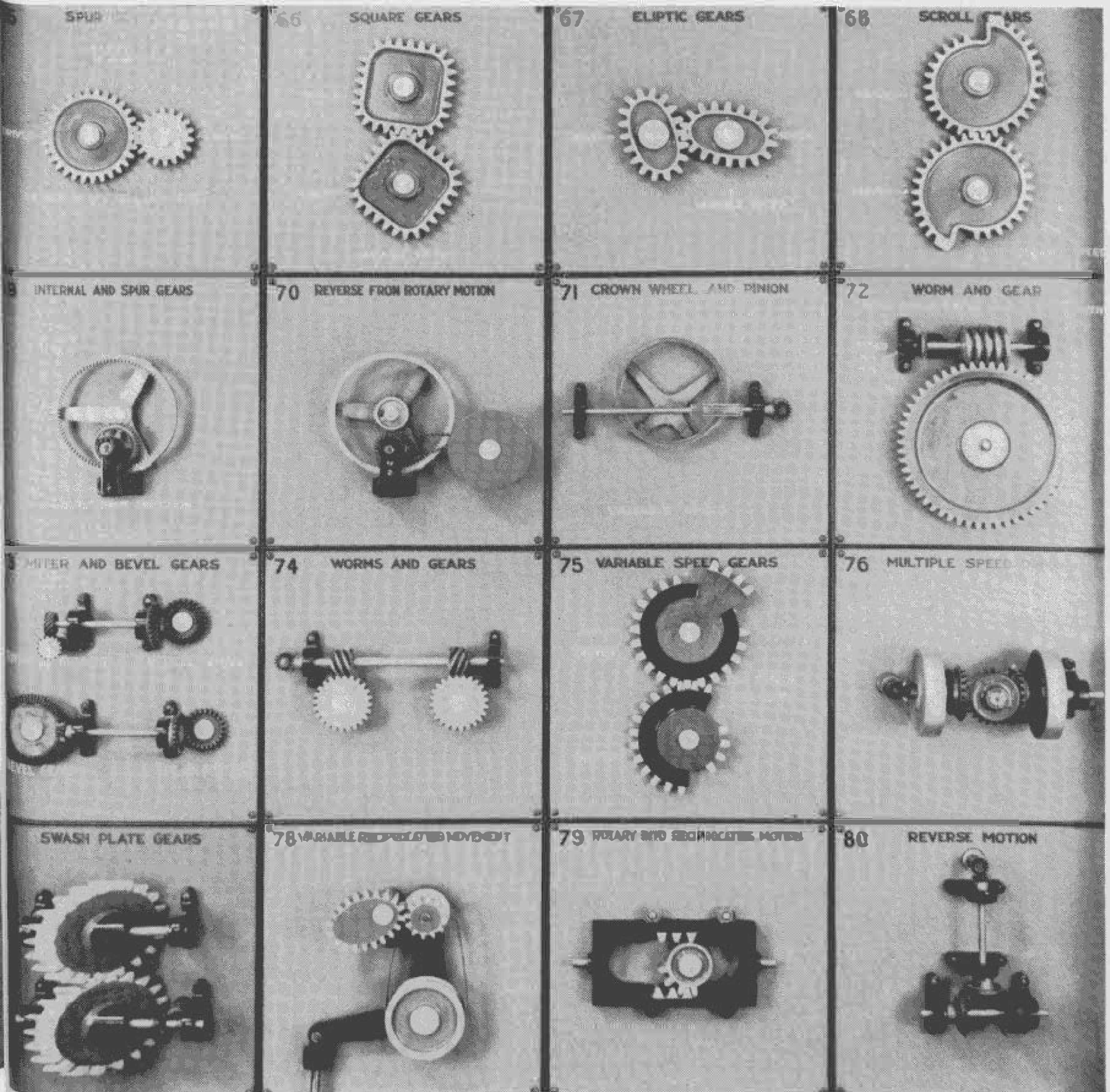
SECTION II, Numbers 17-32. *Universal joints, out-of-line drives, eccentrics, rope and pulley lifts, types of clutches.*



SECTION III, Numbers 33-48. *Countershafts, straight line motions, variable speed devices, cam, and miscellaneous motions.*

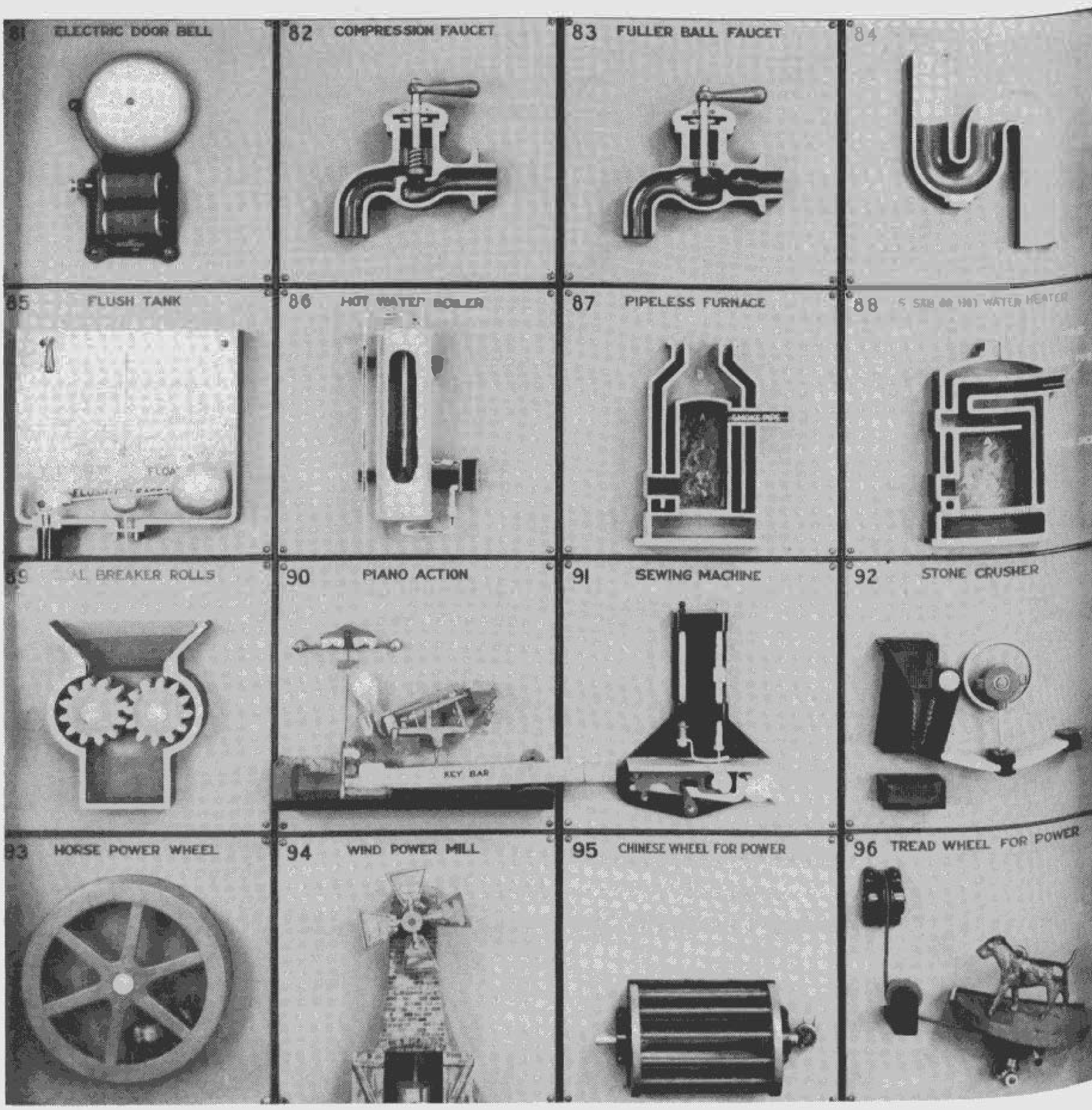


SECTION IV, Numbers 49-64. *Ratchet wheels, drives, stops, and miscellaneous movements used in machine construction; types of power saws.*

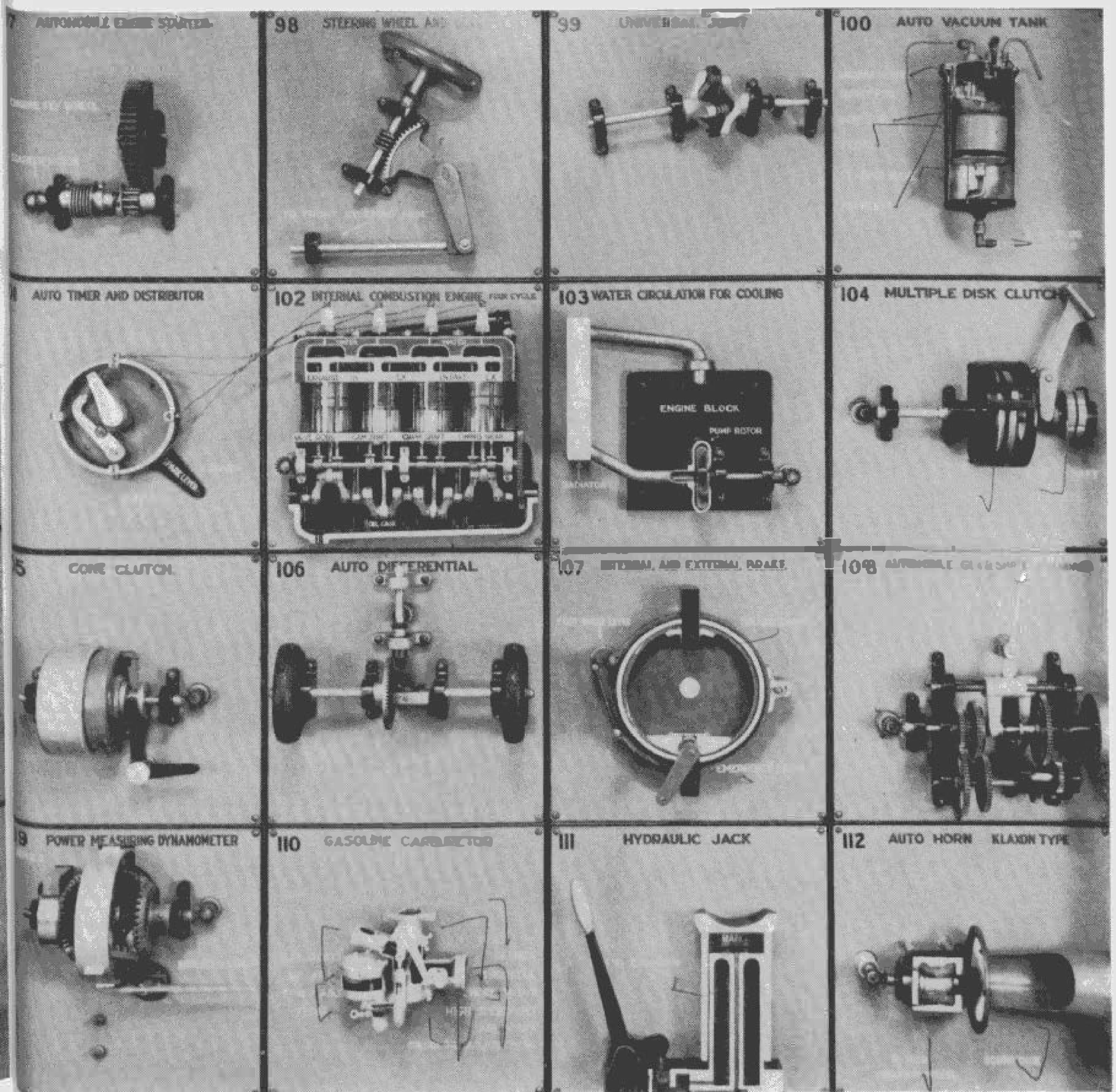


ECTION V, Numbers 65-80. *Gearing group, all types of gearing used in machine construction, ear combinations.*

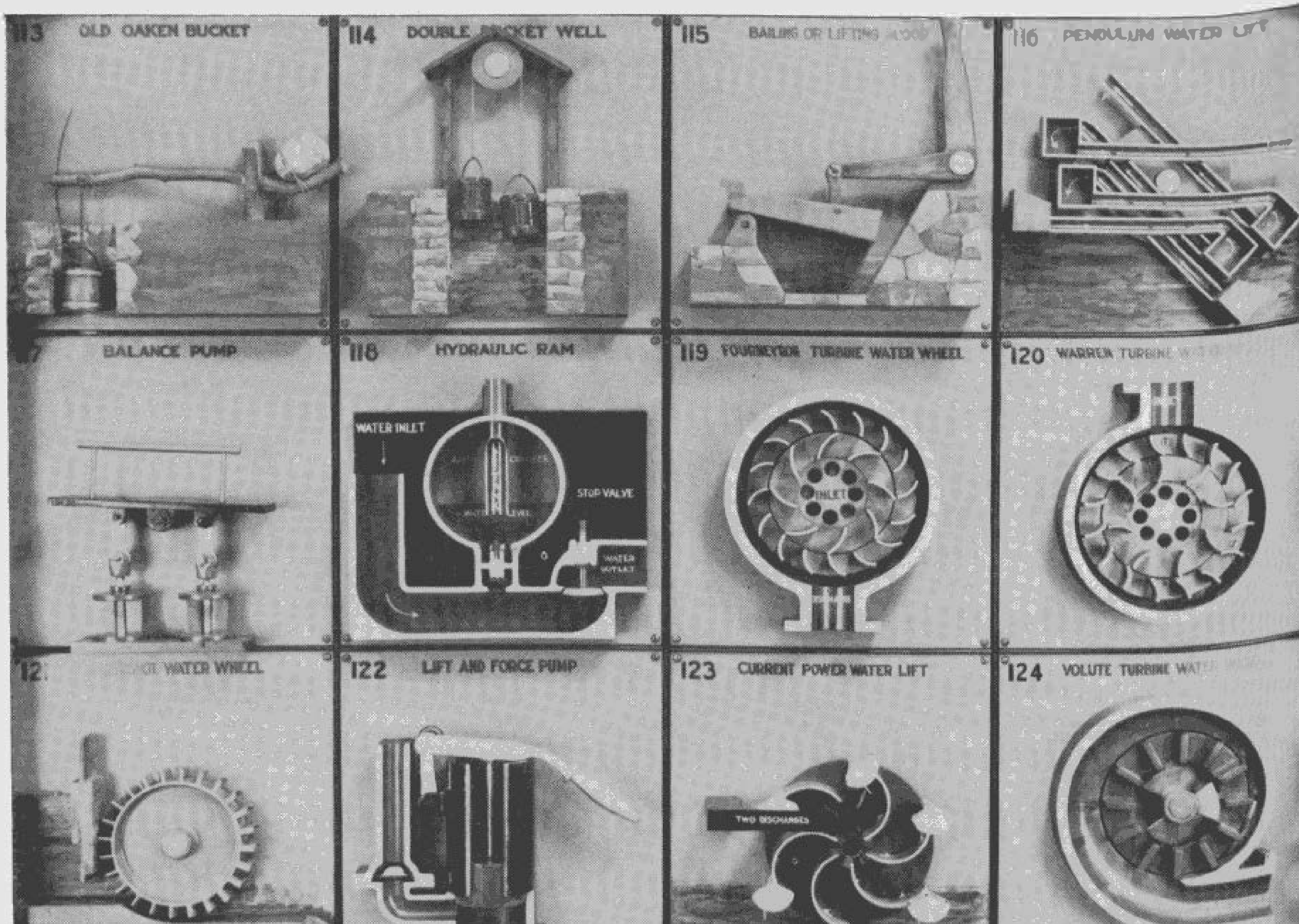
SECTION VI, Numbers 81-96. *Household devices, coal breaker rolls, stone crusher, four early types of power devices.*



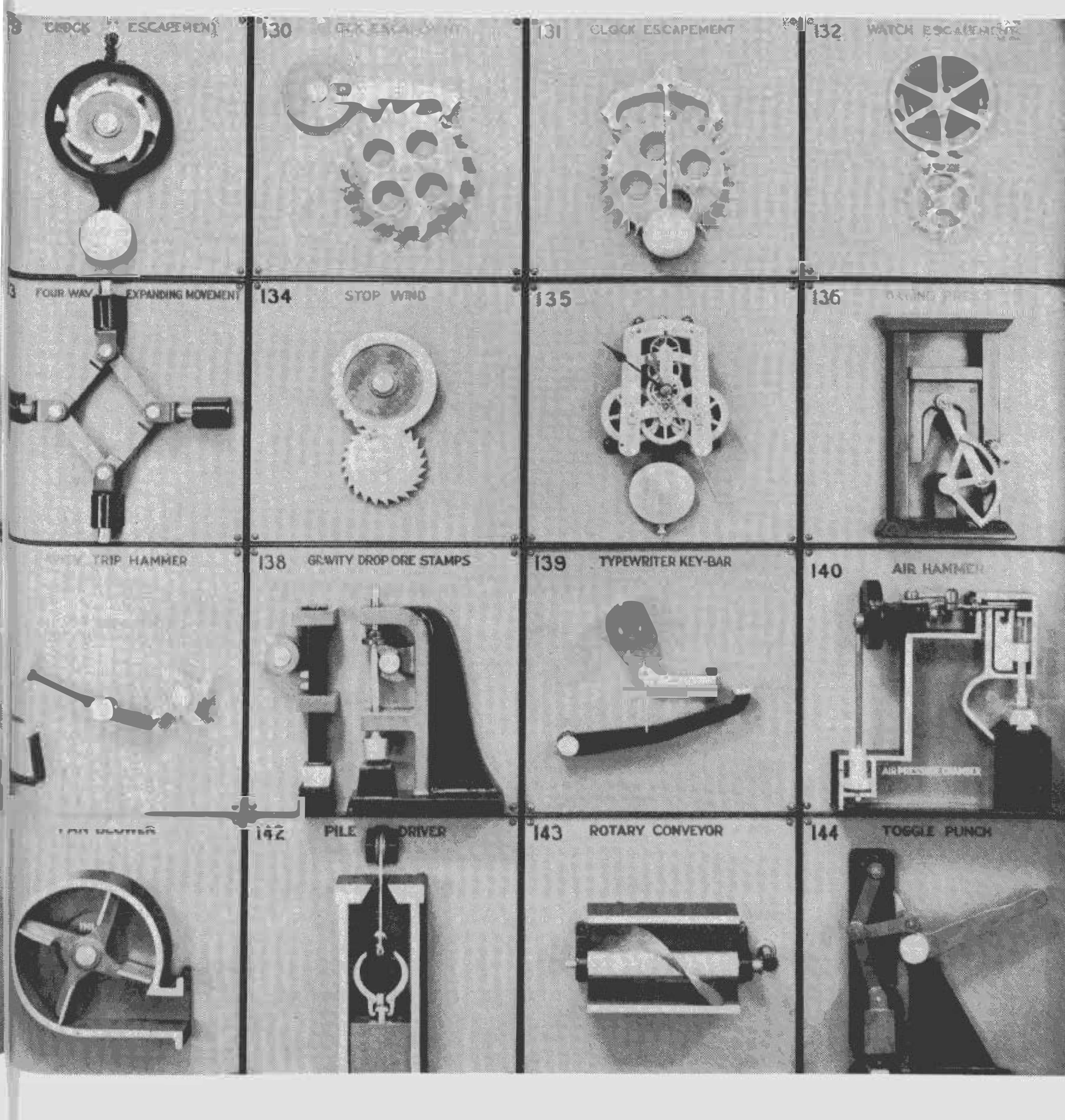
ECTION VII, Numbers 97-112. *Automobile section, showing different parts in detail. Hydraulic ack and miscellaneous devices.*

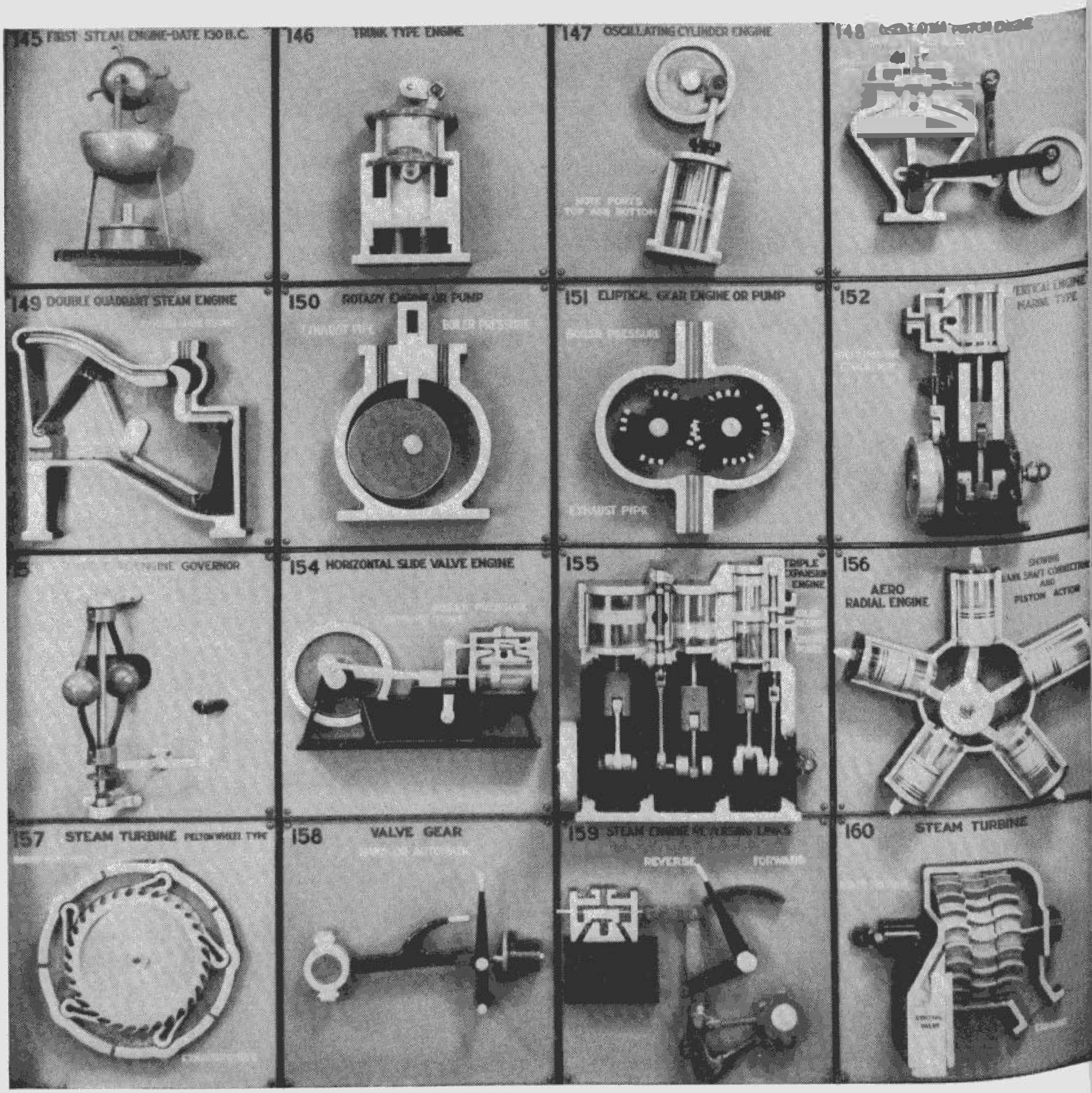


SECTION VIII, Numbers 113-128. *Water handling and water power devices, propeller wheel and steering device.*



CTION IX, Numbers 129-144. *Clock and watch escapements, power stamps and hammers, power nch, rotary conveyer, blower, pile driver, and miscellaneous devices.*





SECTION X, Numbers 145-160. *Steam power group, first engine, various types of steam engines and steam turbines, engine governor, reverse motions for stationary engines and locomotives.*

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