Ballistics, or Throwing Things

By An Artillery Officer.

There is a distinction between chucking and throwing: when you chuck a thing away you discard it as being valueless, the word "chuck" being quite a good dictionary word with that meaning; when you "throw" something, you are interested at least in the direction of your throw, if not also in the distance to which you will throw it. You might, of course, also be interested in direction in the act of chucking—you could say, "I'll chuck that in the garbage bin"—but you would hardly stand back and indulge in careful target practice to throw it into the bin from a distance unless your sporting instinct were strongly developed—or the garbage tin contents strongly developed.

When a cat sits on a wall adjacent to your bedroom window and sings in the moonlight, you do not chuck things at it; quite frequently the objects you project are not valueless to you, and in the morning you may regret that you have thrown them at the cat—that you have made them your projectiles in shots, carefully and deliberately aimed both for direction and range, at your target the cat.

The subject of ballistics is the physics of this careful and deliberate throwing of things at a target. To take one of the most advanced cases first, as an example in brief, we may consider the rifle, or a gun fired by the artillery. A cartridge case contains an explosive of the so-termed "propellant" type such as cordite, which can be ignited and caused to burn very rapidly by the flash from a cap in the base of the case when that is struck sharply; blocking the front of the case is the bullet, or the shell. This combination is placed in the breech of the rifle or gun, and fired; the big volume of hot gas generated in the cartridge case exerts a great pressure on the base of the bullet or shell, which is thus pushed out into the barrel, leaving, therefore, more room for the gas; as the shell is forced further and further up the barrel, the volume into which the gas can get becomes greater and greater, till by the time the shell is forced out of the muzzle the gas has a relatively big volume and can then escape into the outer air. The study of what happens during this time is known as internal ballistics. How much explosive must act as propellant? How long should it take to burn? Should the rate of burning and development of gas be uniform, or should it be arranged to burn more and more rapidly? How far up the barrel should the projectile be before all the explosive has burnt to gas? What should be the length of the barrel compared with its diameter? And hundreds of other such questions are concerned in internal ballistics.

When the shell leaves the muzzle, it is no longer being pushed, and so it is merely being pulled to the earth by gravitational attraction, and being slowed down and pushed by air resistance, just as any other body which is thrown, once it is free of the throwing apparatus. What is the nature of the path it takes? What is the best shape of the head and of the body of the projectile? How will it be pushed off its path? These questions deal with external ballistics.

Now that we have seen how complicated the question can be, we will go back to a simpler case, such as a catapult.

Most of you, even if you have not been allowed to own or use a catapult, have seen one, and possibly used one. It consists of a Y-shaped piece of wood; to the tops of the two prongs of the Y are attached the two ends of an elastic band; in the middle of the elastic band, which usually hangs loosely, is a piece of soft leather, in which the stone or other projectile can be held by the fingers; our *projector* is the catapult, complete; our projectile is the stone. The object is to give the stone a velocity, so that it will move along a path called its trajectory, and hit a target. The stone has a mass, so to give it a velocity means that you have to give it kinetic energy, energy associated with its movement. Most of you know that the kinetic energy of a moving body is equal to half the product of its mass by the square of its velocity, or $\frac{1}{2}mv^2$, where m is the mass and v the velocity. You cannot give it this energy without doing work on it: we cannot create or destroy energy, but can only change it from one manifestation to another, as you learn in the principle of conservation of energy.

The stone held in the curve in the elastic is pulled back, so that we stretch the elastic; we have to do work to stretch elastic, because we move against a force or pull tending to bring it back to the unstretched condition; the further we stretch the elastic, the greater the pull we have to exert, so that we are moving against a force through a distance, and thus doing work. The work we have done is represented as potential energy of stretched elastic; the total work done in stretching the elastic, and hence the potential energy of the stretched elastic which you can get back again by allowing the elastic once again to become limp, is equal to half the product of the final force, or pull required to keep it stretched, and its increase in length. When we now let go the elastic, it contracts, pulling the stone along with it; the stone goes faster and gaster, gaining in kinetic energy as the elastic pulls or pushes it and does work on it; so that by the time the stone is flung clear of the elastic, and the elastic is again unstretched, much of the potential energy of stretched elastic has been transformed into kinetic energy of moving stone, the balance being dissipated directly as heat energy. Off goes the stone; and that is what might be said to summarize the "internal ballistics" of the catapult from the energy point of view.

What about the external ballistics? You learn to aim generally in the direction of the target, but soon learn also to allow for the drop of the stone towards the ground during the time that elapses before it reaches the target. If you drew a straight line from the stone in the catapult to the target you hit, you would find that the stone is fired by you so as to go up at an angle to that line, and hence rise to a highest, or "culminating" point, above it, before dropping back again to cut the line at your target. If fired in a vacuum, so that the resistance of the air to the flight of the stone might be neglected, this path or trajectory would be the curve known as a parabola; those of you who are interested in graphs can draw it simply as the graph of the equation $y^2=4ax$. Or, if you like, you can draw a horizontal straight line, along which a horizontally-projected stone would go but for "gravity"—that is, if it did not keep falling freely under gravity all the time, and thus drop further and further below the line; along this line you can mark off the distance on it the stone would have gone in $\frac{1}{10}$th second, $\frac{2}{10}$th seconds, $\frac{3}{10}$th seconds, and so on, travelling with uniform velocity. Draw perpendiculars down from those marks to represent to the same scale lengths of 2 inches, 8 inches and 18 inches respectively. Then join your starting point to the bottom of those perpendiculars, and you have approximately the curved path of the stone.

Suppose we project it from our catapult with a velocity of 70 feet per second, horizontally; then in $\frac{1}{10}$th second it will have gone *forward* 7 feet, but will have fallen 2 inches; in $\frac{2}{10}$ths of a second it will have gone forward 14 feet, but will actually be below that point by the 8 inches it has now fallen; in $\frac{3}{10}$th second it will have gone forward 21 feet, but will be 18 inches below that point, due to the drop in the $\frac{2}{10}$th seconds. You can see that if you aimed at an object 21 feet away, you would have to aim above the object to allow for the 18 inch drop. As it would take a different time to go 21 feet, depending on the initial velocity of the stone (what we might call its "muzzle velocity"), which would depend in turn on the "strength" of the elastic and how far we stretched it, and on the weight of the stone, you can see that to gauge the drop of the projectile requires a fair experience and skill. You can understand that *knowing* the initial velocity of the stone, and *knowing* the distance away of the target, and *knowing* the slowing down of the stone due to air resistance, we can readily calculate at what angle of elevation to the horizontal we should project the stone; those are the things which the catapult gunner does not know, and it shows good coordination of mental and physical effort to be able to hit the target at various distances so regularly and consistently as he does; also, I am afraid that the small boy often makes his job even more difficult by choosing a moving target.

What about the artilleryman with his gun and shell? The cartridge contains propellant explosive which has been very carefully tested and checked, and carefully and precisely weighed for every cartridge, so that with the particular type of shell used the usual muzzle velocity on firing it in the prescribed type of gun is known.

Some "lots" of shells will give a slightly higher muzzle velocity, some slightly less; the gunner should be told what this alteration amounts to; some guns, worn differently in the barrel, will result in actual variations from the expected muzzle velocity—this can be found by firing those guns in calibration tests on ranges; so that the gunner is like a boy with a catapult who always has the same strength elastic, pulls it back exactly the same distance, and uses exactly the same weight stone, or at any rate knows the corrections to make for slight variations that occur. That means that the gunner knows the initial or muzzle velocity of the shell. With regard to the second point, the range, or distance to the target, the gunner never " guesses " this ; he may have to " estimate " it, but he prefers to use optical instruments called " range-finders ", which tell him how far away is the object at which he is shooting ; with regard to the third point, air resistance, considerable experimental work is done with every new type of shell, or every alteration in shell, even of the head or fuse shape, so that the change in the trajectory due to air resistance is known ; with all this information available, standard " range tables " are prepared and published, which the gunner modifies to embody the particular correction for his gun, for the batch or " lot " of ammunition he is using, and for the prevailing atmospheric conditions such as wind velocity and air pressure which alter the forces opposing movement through the air. Thus he can calculate the angle at which the gun must be elevated so that the shell will rise above the straight line joining gun to target, so that it will fall back and cross it again at the target. There are other factors to be considered, but this is not a lecture on gunnery, but an article of the elements of ballistics, or throwing things.

You may consider that the gunner, having so much preliminary knowledge, is in a much better position than the boy with a catapult ; but whereas the boy can fire up at an angle of elevation of 45° with an initial velocity of 70 feet per second for a range of 50 yards, the gunner is firing with a muzzle velocity of many thousands of feet per second at an object many miles away. He needs every scrap of preliminary knowledge he can get, and then all the acquired knowledge and his intelligence that he can bring to bear on his shooting, to hit the target as often as does our lad with the catapult. Even then it is a big advantage (because the gunner generally cannot even see his distant and concealed target, nor even the bursts of his shells) if a forward observer can observe his ranging shots and then telephone him the corrections in line and elevation to be made to put him on his target.

Let us go back even a little earlier in civilization, before the days of catapults, which were mighty and fairly precise engines of war in Roman days ; consider the savage throwing a spear. He himself is the direct projector in that case ; the energy comes from organic chemicals stored up in his muscles, which was taken from the food he ate. Drawing back the arm and hand holding the spear, he then hurls it forward, applying a force to the spear as long as he holds it, and thus, moving a force through a distance, doing work which is given to the spear as kinetic energy. As soon as he lets it go it merely goes forward with the muzzle, or hand, velocity he has given it, falling freely under gravity just like any other projectile. Experience taught the savage the trajectory of the spear, although he was not aware of the fact that he was carrying out research work on the subject every time he experimented with a new spear or modified his method of holding and of throwing.

In the case of the boy with the catapult, the energy also comes from the food he eats ; this provides the chemicals for his muscles, some of the energy of which he uses up in stretching the elastic ; in the case of the rifle bullet or shell, the energy comes from the chemicals, the propellants, stored in the cartridge case ; in that case we go from chemical energy to heat energy, to kinetic energy of the projectile. When the missile, stone, spear, shell, or shot arrives at its destination, it still has the kinetic energy with which it left its projector, *less* that lost due to air resistance on the way. In the case of stone or spear, that kinetic energy then is expended on doing work on the object struck—it may dent in a jam tin, or it may perforate an enemy's tummy, though fortunately we are now past the barbaric days when we hurled spears at people and hurt them. In the case of the shell, we are not satisfied with the work it can do in coming to rest—we make it contain shrapnel, or high explosive, or gas. The shrapnel shell was itself a little gun or mortar—it had a propellant charge in its base, above which were packed a lot of hardened lead balls ; a time fuse was set so that it burned down to fire the propellant in the base just at the right moment when the shell arrived nearly over its target ; this blew off the fuse, and shot out all the shrapnel bullets with a much higher velocity than they would otherwise have had, and a " good time was had by all ".

The shell containing high explosive may also be fired by a clockwork fuse, or by a fuse set to burn a certain time, so that it will explode in the air or after landing ; or it may have a percussion fuse which fires it the instant the shell strikes its target, or perhaps with a slight delay action. By this means the shell is torn into many pieces, and distributes its casing as a multitude of high velocity missiles round the target, or upheaves the material in the vicinity.

It is a pity that these things must only be applied to war ; the subject in itself is interesting, and there is no reason why, even in a future civilized community, rifle shooting and gunnery should not be the pastime that archery could be today. But it is the old story : the small boy with his catapult is not satisfied to use it on a jam tin—he *will* use it on the cat.