# A Pre-charged Pneumatic and Co2 Primer

Though pre-charged pneumatic and Co2 guns are pretty simple contraptions, a basic grasp of the physics involved with the two operating systems goes a long way towards getting the most out of these air and gas gun designs. The different physical properties of the two compressed mediums instill profound differences in their characteristics as fuels for the launching of projectiles. Your author will attempt to endure an extreme aversion to technicality long enough to address persistent misinformation about compressed air and carbon dioxide gas operation and performance.

Pre-charged pneumatics and Co2 guns are of very similar design, but with valve and hammer spring tensions adjusted for the different chamber pressures at which the two propellants operate. Contemporary pre-charged pneumatic guns typically operate at pressures of 2,000 to 3,000 PSI, as opposed to typical Co2 pressures of 600 to 1,200 PSI.

Co2 guns exploit the fact that liquid carbon dioxide trapped in a sealed chamber is in a state of reversion back to compressed gas; or perhaps more accurately, gaseous vapor. Co2 chamber pressures also relate directly to the temperature of the gun, which is affected not only by ambient temperature, but also the refrigeration effect of shooting the gun. However, given a constant temperature, the chamber-pressure (that drives the projectile) remains fairly consistent while there remains liquid Co2 in the chamber. Chamber pressure then falls rapidly as liquid Co2 becomes depleted.

*The L D custom Crosman is a temperature-tolerant Co2 pistol of excellent power and accuracy.*

Any size chamber charged with liquid carbon dioxide returns many more shots than if charged with compressed air. This quality allows relatively high shot counts from relatively small chambers; a characteristic that makes compact Co2 guns possible.

Since Co2 gun operating pressure and muzzle velocity varies significantly with operating temperatures, temperature sensitivity is the Achilles heel of Co2 guns. A difference of only ten degrees Fahrenheit noticeably affects pellet velocity and point of impact. A 20 to 40 degree temperature variable wreaks absolute havoc on trajectories. This is why Co2 guns have largely fallen out of favor for serious competition.

Though much more resistant to weather-related ills, pre-charged pneumatic guns are not affliction-free. Compressed air in a sealed chamber maintains consistent pressure only as long as no air escapes. In other words, only until the gun is shot! So if chamber pressure falls *with each shot*, how is it that PCP's display any velocity consistency whatsoever? This is where the going gets a bit technical.

So as to not over-complicate matters any more than necessary, this discussion will concentrate on unregulated PCP's. Regulated guns are subject matter for another article altogether.

As chamber pressure falls with every shot of an unregulated PCP, there is less pressure against the exhaust valve holding it closed. Consequently, as chamber pressure falls, the force of the hammer-blow opens the exhaust valve slightly longer in stroke and/or duration, allowing a greater *volume* of air to escape to drive the pellet; providentially offsetting the slightly lower *pressure* of air released. Since a combination of pressure *and* volume drives the pellet, this lower-pressure/higher-volume of air exhausted with each shot averages out to relatively consistent pellet velocities over a certain *power-band* of worthwhile shots per charge. At some point chamber pressure drops low enough that the hammer-blow is opening the valve as much as it can open, after which pressure *and* volume of air decreases with each shot and velocity starts a rapid decline.

*Perhaps counter-intuitively*, excessive chamber pressure actually results in reduced velocity; a situation commonly referred to as 'valve-lock'. Too-high chamber pressure exerts so much pressure against the valve that the hammer blow cannot open the valve enough to propel the pellet to optimum velocity. Excessive chamber pressure can indeed lock the valve (completely) from opening from the force of the hammer impact. However, for our purposes the term 'valve-lock' is used to describe the condition where velocity suffers as chamber pressure impedes the hammer adequately open the valve.

Which brings us to the next pertinent subject- *'bell-curve power-band'*.

We now know that a combination of pressure and volume drives the pellet. Consequently PCP's can return fairly consistent velocities over a certain range of

chamber pressure because more volume of air is expelled as the pressure of that air falls with each shot. Therefore, in order to maximize the number of acceptable shots per charge possible with any given pre-charged pneumatic, it is important to discover at what fill pressure the gun starts exhibiting symptoms of valve-lock. But before doing so, it is helpful to decide how much velocity extreme-spread one considers acceptable.

For instance, let's say you can live with a velocity extreme-spread of 30 feet-per-second. Assuming you know the recommended charge pressure of the gun, charge it to a pressure about 300-400 PSI less than recommended and chronograph the velocity over several shots. That fill pressure should produce near peak velocity, an important first step in discovering optimum charge pressure. Within five to ten shots you should see a pattern developing of some kind; either velocities are rising, falling, or remaining pretty static. Since you are searching for the peak velocity, if velocities are rising or remaining constant, continue shooting until velocity begins falling for several shots. Record the peak velocities achieved, and re-charge the gun to a pressure 100 PSI higher than before. **Continue chronographing and re-charging the gun to higher pressures until you discover the fill-pressure that returns velocities 30 feet-per-second less than peak velocity.** That is the optimum fill pressure. However, **never fill a gun to more than 10% higher pressure than manufacturer recommendations.**

Charge the gun to its sweet-spot fill-pressure, then chronograph and record each shot while velocities climb, level off, and fall again to a point 30 FPS below peak velocity. At that point you've found the optimum fill-pressure to return an optimum 'bell-curve' power-band with a velocity extreme-spread of the desired 30 feet-per-second. The goal is to eke-out the maximum number of useful shots by charging to an ideal pressure (of slight valve-lock) that produces 30 FPS less than peak velocity, and shooting until velocity peaks and drops again to 30 FPS below peak velocity. That is the bell-curve. Quite likely, optimum fill-pressure will not be exactly that recommended by the manufacturer. Just as likely, you will enjoy a higher shot-count per charge than if operating at the manufacturer's exact recommended fill pressure.

Now, after all that techno-babble… I mean 'fun', understand that any change in hammer-spring or valve-spring tension alters the mechanical dynamics; hence changing the sweet-spot fill-pressure and bell-curve power-band. Even if the results achieved were not satisfactory, we have at least quantified the gun's performance with a reference point from which to proceed.

This conjures two questions. What happens when we change hammer or valve-spring tension(s), and how do we tune for desired performance? ***Thankfully***, both questions can be answered with just a little more information.

A stronger or weaker hammer-spring respectively increases or decreases the impact energy of the hammer against the valve, allowing longer or shorter opening of

the valve, resulting in more or less pressure and volume of air expended to drive the pellet to higher or lower velocities. Of course any change in the valve spring affects the pressure holding the valve closed and the hammers ability to open the valve against said back-pressure. Side-effects of any change in either hammer or valve spring tension are changes in fill-pressure, bell-curve power-band and number of shots per charge.

To summarize the effects of changes in valve or hammer-spring tension- stronger hammer-spring or lighter valve-spring tensions produce increases in velocity and fill pressure, and vice-versa. BOOM… there it is!

That bit of information allows tuning of pre-charged pneumatics for ideals in velocity, fill pressure or power-band. As these three factors inter-relate and must abide by the laws of physics, in most cases the best we can hope to achieve is the ideal in one of the three areas; perhaps also with positive effects on one or both other areas.

Much of the information presented above also applies to Co2 powered guns; however we have little control over chamber pressure beyond obtaining an optimum Co2 charge. To a point, gas-gun muzzle velocities increase as temperatures rise. However, as most Co2 guns are designed to operate at typical chamber pressures of 600-1,200 PSI, it is possible to experience valve-lock in hot temperatures as chamber pressures increase to as much as 1,500 PSI or more. This situation is more common with bulk-fill guns filled to maximum charge density, but also occurs in cartridge guns (especially those of meager power). Powerful Co2 guns are less prone to exhibiting symptoms of valve-lock in extreme heat than guns of moderate power. In fact, a heat-temperamental Co2 gun can be made less so through installation of a stronger hammer spring and/or lighter valve spring.

Since most compressed air and Co2 guns' hammer-springs are somewhat easily accessed, much tuning can be accomplished pretty easily with changes in hammer-spring tension. Delving a bit deeper into the innards, one can also access the valve-spring to experiment with balancing the interaction between the hammer and valve springs. More ambitious tuning can be accomplished by smoothing contours, angles and passageways between the air chamber and pellet chamber, much as an internal-combustion engine tuner ports and polishes a cylinder head for better flow.

Though PCP and Co2 gun tuning is pretty simple stuff, as in many seemingly simple endeavors, the devil resides in the details. While much can be accomplished with basic hand tools, the most necessary tools for airgun tuning are a chronograph and heapin' helpin's of patience and persistence. In any search for the ideal performance envelope, it is not unusual to disassemble and reassemble the piece half a dozen to a dozen times, testing for performance each time.

Some of the author's more enlightening air and Co2 gun tuning odysseys are described in the foot-notes for the Galway Fieldmaster, Shin Sung Careers and

Sportsman QB77 sections of the velocities testing chronicled elsewhere in this book. Ultimately successful, those particular trials and tribulations were excellent, first-hand learning experiences. Crash courses in airgun tuning, you might say.

*Trials by fire*, I might say.

*Virtue of its power-wheel and accessible hammer spring, the Sumatra is a one-gun physics lab.*

## It’s a Gas, Man

For some, carbon dioxide is much more than an industrial waste-product to blame for one of the planet’s biggest threats. Vilified as this heavy gas may be in our age of environmental enlightenment, some airgunners recognize the beauty of Co2 for its properties as a lovably quirky airgun propellant. And while other shooters might turn up their noses to this gaseous matter as unworthy of serious airgunning consideration, for those that appreciate it, Co2 powers many of the most interesting airgun designs ever conceived. The length of this chapter testifies to the author’s feelings on the subject.

Some of the highest quality and most beautiful of all Co2 guns also happen to be the earliest examples. The fantastic Giffard ‘Carbonic Gas’ rifles and pistols were wonderful works of nineteenth century gun-making art. As such, and considering their 1890’s vintage and low ‘production’ numbers, surviving Giffards command serious money in any condition. These French hand-made and engraved pieces of shooting history have incredibly sexy profiles that absolutely *ooze* ‘exotic’! Extremely rare and rightfully precious, one needn’t examine a mint example to experience feelings of awe and wonderment at the level of craft manifest in these jewels of Old-World antiquity.


*The fantastic French-made Giffard Carbonic Gas rifles and pistols were produced around 1890 in 6mm and 8mm caliber (and maybe others). Liquid Co2 not being commercially available at the time, the chamber was filled with dry ice that reverts to liquid/gaseous Co2 in a sealed chamber.*

Though not exactly pea-shooters, the Giffards were certainly not powerful enough for use as weapons of the chase, war or self-defense. No, these fantastic Co2

rifles and pistols were apparently just expensive toys of the wealthy elite. But what impressive toys they were. The past-tense is purposely applied here, as I've not heard a single report of current owners actually shooting one; much less seen any performance figures! Too bad, as it would be quite interesting to compare these century-old Co2 guns' performance to the wide variety of gas guns produced today and in America's 'golden age' of Co2 from the late 1940's into the eighties. Call me crazy (you wouldn't be the first), but near the top of my 'when I strike it rich' list is not only replicating a Giffard, but shooting the hell out of it!

However this article is not about collector guns so precious most of us will never have an opportunity to see or handle one, much less actually shoot it. No matter. Such untouchable collectors' items couldn't possibly outperform any number of modern Co2 guns or affordable American collectables. In fact when it comes to 'bang for the buck' performance, shooting pleasure and ease of customization, modern and vintage Co2 'burners' represent some of the best bargains in the airgun universe.

Condolences must go to readers inhabiting cold climates, since Co2 pressure and performance falls with the mercury. Shooters residing in warmer climes tend to appreciate the idiosyncratic properties of Co2 more than those who seldom see temperatures north of 70 degrees Fahrenheit. No doubt Co2 gun sales are substantially more vigorous below the Mason-Dixon Line than above it, with good reason. Southern airgunners savor the dog days of summer for the powerful effect on their gas-gun arsenals, while their northern brethren generate precious body-heat with multi-pump and spring-piston guns.

Co2 guns cover an extremely wide range of styles and performance, from cheap plinkers to expensive target guns to medium-game-capable big-bores. However the vast majority of gas guns ever produced fall in a medium power range of 3-6 foot-pounds for pistols and about twice that for rifles. Considering the torrid pace of the current airgun power race, these are pretty sedate power levels. But as in other race scenarios, harnessing moderate power in light, compact vehicles can produce some pretty exhilarating power-to-weight ratios.

Current Crosman and many vintage Co2 pistols produce five to six foot/pounds of muzzle energy in smaller, lighter, less expensive packages than other power-plant designs. This power level is a comfortable minimum for prey to the size of jackrabbit, but there are occasional reports of raccoons falling to close-range encounters.

*Many current and vintage Co2 pistols can be excellent small-game arms and benefit from simple to elaborate gunsmithing. This .35 caliber custom sports a Crosman trigger and 2250 chamber, bulk filling, Crooked Barn breech, a power adjuster, coco-bolo grips and red-dot scope. It averaged 7/8" groups at 25 yards with 58 grain round balls at 325 FPS/13.6 FP.*

With simple and affordable gunsmithing techniques, many of these same pistols can be hopped-up into the 8-10 foot-pound range; a power level stretching maximum ranges for small game, though not qualifying such guns for larger (medium) game. If accurate enough (and most are), an 8-10 foot-pound pistol can be effective to near forty yards on rabbit-sized critters. That said, game larger than jackrabbit should not be attempted. And though there now exist occasional custom-built pre-charged pneumatic pistols capable of taking medium to large game, even highly modified Co2 pistols do not possess such potentials. With chamber pressures peaking at about 1200 PSI in temperatures tolerable to humans, gas pistols simply cannot muster enough projectile energy for realistic pursuit of game heavier than about ten pounds. Nevertheless, their excellent small game capabilities come in smaller, handier packages than other air pistol designs of equal or greater power.

Pre-charged pneumatic pistols require long barrels, large chambers and big bores to graduate beyond the small game field. The sole exception to the big-bore part of that equation is the Evanix AR6; a .22 caliber PCP revolver capable of up to forty foot-pounds and medium game. However a hunt or shooting session with a scoped AR6, FX Ranchero or Falcon Raptor pistol will heighten one's appreciation for the

portability and holster-ability of a Crosman, Benjamin or Sheridan Co2 pistol. Though the author is not at all adverse to pre-charged pneumatics, when the menu calls for squirrel and rabbit, the shoulder-holster carries a custom Crosman, the hands a complimentary rifle, and the pockets bulge with twelve-gram Co2 cartridges.

*Though not a particularly large PCP pistol, the Falcon Raptor dwarfs a Crosman 150. The custom Crosman gets 450 FPS/6.4 foot-pounds, the Raptor 650 FPS/13.4 foot-pounds. Both guns shoot 1/2" groups at 25 yards, but the Falcon almost doubles a good shooter's effective range.*

As further testament to gas-gun capabilities, the world record score for ten-meter air pistol competition is still held by a Co2 pistol. Ten-meter being an indoor competition, temperatures are controlled to comfortable levels, minimizing Co2's disadvantage. As technically advanced as pre-charged pneumatic target guns have become, the standing ten meter pistol world record proves gas guns as inherently accurate as any design.

My extensive velocity and accuracy testing, state champion trophies and national record certificates also confirm Co2 gun performance potentials beyond the plinking role many shooters associate them with. Aforementioned awards were captured in outdoor temperatures against national caliber shooters employing the finest guns powered by air rather than gas, and costing magnitudes more than the Co2 guns that whipped 'em.

A much-beloved Sears Ted Williams 'Match Rifle' variant of the timeless Crosman 160 Co2 rifle snatched a Texas State Champion trophy and two NRA national record

certificates from fields of experienced silhouette competitors wielding fine spring-piston rifles from Air Arms, Weihrach and Whiscombe. Not only was the Sears rifle the only Co2 gun in the field, but the only .22 caliber; effectively shattering prevailing attitudes about proper silhouette rifles and caliber.


*This 1950's vintage Ted Williams 'Match Rifle' captured a state championship and two national records. The 2-7X scoped classic weighs a svelte 6 ¾ pounds; barely half the status quo.*

No-one in their right mind would bet on a .22 Czechoslovakian Co2 pistol against the finest Hammerli, Walther and Feinwerkbau target pistols costing many times the price of the lowly Brno Tau 7. However, I'll take that bet!

In the days pre-dating tunnel-type peep sights and the 'taco hold' that now dominate Iron Sight Class, my first two attempts at the Texas State Air Pistol Silhouette Championships with a .22 Tau Co2 pistol fell just short. Having lost the Y2K state championships by one point and the 2001 championship TIE by shoot-off loss, with great determination I posted high score on day one of the 2002 championships with a 31/40. Three other shooters posted 30/40's to set the stage for a tough battle on day two for Texas State Champion in Open Sight Air Pistol. A restless night brought the supposition that at least one of those shooters would probably rise to the occasion to shoot a 33 on day two. I would need to shoot at least a 33 to avoid another 'close' disappointment.

Two antagonists actually shot 34's. But in buckling down like never before to shoot my personal best iron-sight score, so did I! The Tau's two-day aggregate of 65/80 bettered a national-caliber field of 22 shooters using some mighty fine air pistols; all .177 caliber and all air-powered.


*The .22 caliber Tau 7 bested a field of 22 shooters to capture the 2002 Texas state championship.*

Unfortunately its plain walnut does little to compliment the otherwise awesome Tau, now deserving of something special to commemorate the memorable performance. Not inclined to purchase custom grips, I took a unique tact in commemorating one of the finest memories of my airgun affliction. Since the 500 foot-per-second .22 Tau also possesses admirable small-game potentials, it seemed the customization should reflect its field worthiness. It was a labor of love.

*Prairie rattler adornment nicely commemorates the .22 Tau's Texas state championship.*

The 2007 Republic of Texas Field Target Championships included Texas' first Pistol Field-Target competition. Some old coot entered with a pistol home-made from a 1950's-vintage Crosman 180 rifle. When the Co2 settled, that 180 pistol conversion, aka- 'Frankenpistol', had mauled the field by a comfortable margin.


*The home-made 180 pistol captured Texas' first Pistol Field Target Championship.*

Not a finicky eater, Frank devours any high-quality pellet with great relish. Producing over 500 FPS and eight foot-pounds, in shooting five consecutive five-shot groups, The Beast has averaged .37" c-t-c five-shot groups at 25 yards and .74" at 50 yards. In recording such impressive average group sizes, it has also recorded five-shot groups measuring a scant .12" c-t-c at 25 yards and a mere .53" at 50! This is the smallest 25 yard pistol group I've achieved in decades of testing hundreds of air guns. For better perspective, the 1/8" twenty-five yard group translates to less than one-half minute-of-angle. Not too shabby… for a pistol home-made from a fifty-year-old Co2 rifle.

Given such excellent power and accuracy, Frank's voracious appetite of only fifteen to eighteen full-power shots per cartridge is easily forgiven. Its dual-power cocking offers instant power moderation and improved Co2 economy, but is seldom used.

Frankenpistol performs similarly in power and accuracy to an LD custom Crosman Mark 1. Aptly named after its co-creator Larry Durham, the LD Co2 pistol is an excellent choice for the airgun pistolero interested in small-game hunting, silhouette or pistol field target competition, but not interested in building a custom them self.

Nowadays Crosman offers several Co2 rifles and pistols worthwhile in stock form, which also benefit greatly from a myriad of after-market goodies available from a busy cottage industry built around Crosman's offerings. In fact Crosman now offers many custom features on several of its guns, available by special order from the Crosman Custom Shop at reasonable prices.

At least a few airgunsmiths convert certain Co2 guns to run on high-pressure air with some success, albeit sometimes mixed. Crosmans are often the platforms of choice; however the QB series of Co2 rifles are also popular for HPA conversion. My converted QB77 rifle was a good example of the mixed success, as it returned a useful (for com-petition) power-band of only about eighteen shots per 2,000 PSI charge. This limited shot count is not uncommon with Co2 to PCP conversions, owing to smallish chambers and (often) less-than-optimally-balanced hammer and valve springs.

Another Co2 rifle that has been converted to PCP with some regularity and success is the Hammerli 850/RWS 850. With its bolt-action repeating mechanism and 88 gram disposable Co2 bottle paralleling (under) the barrel, no wonder some might see Theoben Rapid design similarities and make the mental leap that a paintball-type high-pressure-air bottle might be adapted to replace the big Co2 bottle. The result is something of a poor mans' Theoben Rapid that performs well for a very reasonable price.

To its credit, Crosman recognized an opportunity to recapture some of the adult airgun market with its Benjamin Discovery rifle. Evolved from the 2260 Co2 rifle, in a stoke of marketing forethought, Crosman made the Discovery a 'Dual Fuel' gun capable of Co2 or air power. A big hit in the marketplace, the light, handy, reasonably priced Discovery also benefits from after-market options similar to those for their other guns.

While an excellent plinker and hunter, attempts by many to make it a viable field-target rifle have exposed some inherent weaknesses; those being (primarily) the pencil-thin barrel and plastic trigger housing inherited from its 2260 lineage. The light barrel is simply not as stable as necessary for the demanding sport of field-target, where even minor shifts in zero are catastrophic. And while the trigger-action can be improved with everything from simple trigger-smithing to aftermarket sears, the plastic trigger housing 'houses' gremlins akin to the thin barrel; ultimately limiting the degree to which a fine trigger action can be achieved and maintained.

Thankfully Crosman had an ear to the grapevine, and with a little help from serious airgunners they developed the 'Marauder' Dual Fuel rifle. Suffice to say Crosman learned its Discovery lessons well. The relatively inexpensive Marauder is a fine bargain that quickly made major waves in field-target competition, hunting fields, and the market-place. The subsequent Marauder pistol has proven to possess all the fine attributes as its parent rifle.

Crosman recently introduced another reasonably-priced PCP pistol evolved from Co2 lineage. Considering airgunsmiths have been converting Crosman Co2 pistols to air for a while, it's no major epiphany there was a market looming that Crosman might as well exploit. Again outside the scope of this chapter, thankfully the Crosman 1700/1701 'silhouette' PCP pistol got a better trigger group than their Co2 pistols.

Not resting on their laurels and success of their excellent PCP rifles, and presumably responding to a certain amount of demand, Airforce Airguns makes an adapter to power their rifles on Co2. With reports ranging from favorable to highly enthusiastic, they now market some of their models as Co2 guns. While velocities and energies suffer considerably when using Co2 power, shot counts increase dramatically.

My first pre-charged pneumatic was a Galway Fieldmaster, one of the first production PCP's available. Also designed to operate on air or Co2, I used it with both propellants to learn many physics lessons by monkeying with hammer stroke and mass, and hammer-spring and valve-spring tensions. Details and results of the experimentation are recorded in the velocities section of this work.

*One of the first modern PCP rifles produced, the Galway Fieldmaster was marketed as a PCP or Co2 rifle. After copious amounts of tuning and gunsmithing, it worked well with both propellants.*

A myriad of Co2 pistol and revolver firearms replicas are available and being constantly introduced; a situation that suggests a healthy and expanding Co2 gun market. That many are of adult quality, heft and price also suggests that Co2 is not just for kids; a role the propellant had seemed to slip into during the spring-piston and PCP growth era of the 1980's through Y2K. With respected companies like Hammerli, RWS, Umarex, Colt and Beretta jumping back on the Co2 bandwagon, the future is bright for Co2 fans.


*Though no competition pistol, the Smith & Wesson 586 by Umarex is possibly the nicest quality Co2 firearm replica on the market… maybe ever!*