

As-Built Bill of Materials and Cost

Author	Mark1 AI instance, driven by Chris Mullins	Date	2026-09	Revision	v0 draft
Configuration	purchases 2017–2021 as recorded in the design workbook (prices as paid, USD)				
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Machine at a glance	
Type	Classical single-dee proton cyclotron, internal beam only
Magnet	H-frame, 1018 steel, 8 in poles, 1.42 in gap (as built); 538 turns of ¼ in copper refrigeration tubing, air-cooled
Field	0.851 T maximum at 55 A; operated at 570–596 mT in the beam era
RF	~9 MHz, ~50 W solid-state chain; dee voltage ~800 V nominal, uncalibrated
Chamber	304 stainless ring, ≈9.75 in bore, 1.000 in interior, ten KF16 ports, two 0.200 in lids
Vacuum	Edwards SI100 diffusion pump + 3 cfm rotary; gate 1×10 ⁻⁵ torr (5.0 V on the ion gauge)
Ion source	Tungsten filament (ES-020) in hydrogen at ~10 ⁻⁵ torr, mass-flow controlled
Detection	Copper collector ("Faraday cup") on a linear translator, Keithley 617 electrometer
Best beam on record	–3.1 nA vs –0.55 nA background (5.6×), 596 mT / 9.033 MHz, 2023-10-14; ~150 keV-class computed
Built / operated	2017–2018 build; 176 logged runs on 44 dates, 2018-12-16 → 2025-02-02

1. Purpose and scope

This note is the money record of the Mark I: what the machine is made of, what each part cost, where it came from, and how the total spent relates to the total embodied in the machine. It is written for someone budgeting a similar build. It draws no build-versus-buy conclusions; those are deferred to a later note.

Three sheets of the design workbook (cyclotron9.xlsx) carry the record:

Sheet	What it is	Rows	Total (USD)
budget	The pre-build budget, written in 2017 before most purchases	22 lines	12,232
BOM	The builder's categorized as-built bill of materials, by subsystem	75 priced lines in 8 blocks (a consumables block sits outside the total)	11,933.31
purchases	The raw purchase ledger: every order, with vendor and price	327 priced rows	20,374.72

The BOM sheet is the builder's curated view of what went into the machine; purchases is the ledger of what was bought. They were kept separately and disagree in places. Where they disagree this note says so, treating the ledger as the record of money spent and the BOM as the record of what the machine contains.

Three limits of the record: **the ledger has no dates** (the first hardware-store runs are May 2017, the frame-steel quote is 24 July 2017, and the last cluster — a second filament pack, the 102 L hydrogen cylinder and its fittings — belongs to the 2021 MFC era); **prices are as paid, 2017–2021 US dollars**, with tax and shipping recorded inconsistently, and nothing has been re-priced (§8); and **a few items now on the machine are in neither sheet** (§5.5).

2. Headline: budget, BOM and ledger

	USD	Relative to the BOM
2017 pre-build budget	12,232	+2.5 %
As-built BOM (builder's categorized view)	11,933	—
Purchase ledger (everything bought)	20,375	+8,441 (+71 %)

The budget and the BOM agree to within \$300, which says more about the budget's provenance than about forecasting: several budget lines (diffusion pump 379, magnet supply 513, cart 473, electrometer 600) are the prices of items already found on eBay when the budget was written. The lines that were real forecasts — iron, copper, chamber, welding — landed within 25 % in both directions, and the misses cancel.

The ledger is 71 % larger than the BOM. §5 classifies every one of its 327 rows and accounts for the whole difference: about a third is hardware that is on the machine but never made it onto the BOM sheet; the rest is spares and re-buys, tools, consumables and abandoned design branches.

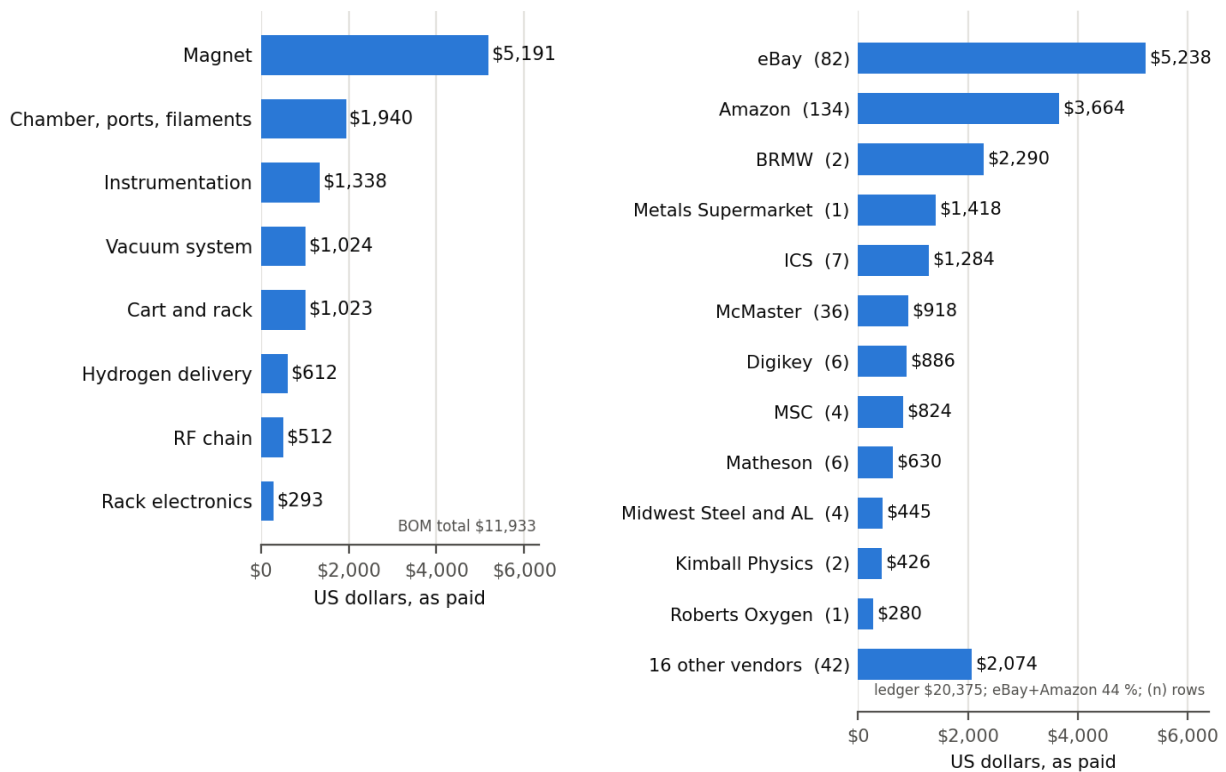


Figure 1. Left: the as-built BOM by subsystem (design workbook, BOM sheet; prices as paid) — the magnet is 43 % of the embodied cost, and the chamber block includes the ion-source filaments. Right: the purchase ledger by vendor, all 327 rows (purchases sheet), row counts in parentheses; the pooled group is Ham Radio Outlet, TW Metals, Home Depot, Harbor Freight, Onlinemetals, SPI, Stockcar Steel, Lowes, UC Components, Discount Steel, Grainger, Accu-Glass, Advance Auto, MDC and The O-Ring Store, plus 16 rows with no vendor recorded.

2.1 Budget lines against what was built

The budget and the BOM use different categories; the table regroups the BOM lines under the budget lines they answer to.

Budget line (2017)	Budget	Corresponding BOM lines	BOM
Iron	1,842	Frame steel, poles, pole extensions, pins, shoulder screws	2,331
Copper wire	1,350	Two orders of ¼ in ACR tubing, fiberglass sleeving, Kapton tape	1,546
Water cooling	280	None — never installed (§5.4)	0
Welding	1,500	H-frame machining (BRMW)	629
Magnet power supply	513	Sorensen DCS55-55M62	513
<i>not budgeted</i>	—	Welding cable, lugs, coil-frame aluminum sheet	172
Chamber	1,000	Chamber machining, pipe, lid plate, O-rings, lid screws, epoxy, dee	1,428
Chamber fittings, feeds	500	Ports (lump 200), weld-sock flanges	300
Ion source	500	ES-020 filaments (one 10-pack)	212

Budget line (2017)	Budget	Corresponding BOM lines	BOM
Diffusion pump	379	Edwards SI100	379
Forepump	0	Harbor Freight 3 cfm two-stage	150
Vacuum valves + fittings	900	Rough-pump adapter, "other fittings" lump	170
Vacuum gauges	250	GP-275, GP-354, MKS 901P	247
Pump oil	75	DC-704, Robinair	78
Hydrogen, regulator	500	Lecture bottle, regulator, washers, needle valve, tubing, fittings, PVC mount	612
RF generator	360	Siglent SDG1032X	359
RF amp	180	5 W preamp, 50 W HF amplifier	171
Matching network	400	LDGAT-200PRO-II, ammo box, parts, Garolite rod	291
<i>not budgeted</i>	—	Coax and adapters (lumps)	50
Electrometer	600	Keithley 617	600
<i>not budgeted</i>	—	Siglent SDS1202X-E oscilloscope	379
Cart	473	Durham HET-3048 service truck	473
<i>not budgeted</i>	—	Wood base: 4×4 timbers, stainless rod, nuts, washers	137
Rack	430	Samson SRK21 stand, shelves, blank panels	413
<i>not budgeted</i>	—	Rack electronics: DC supplies, panel meters, switches, fuses, timer, bias supply	293
Supplies	200	(kept outside the BOM total)	—
Total	12,232		11,933

"Welding 1,500" was the allowance for having the frame fabricated; the frame was bought as four cut bars and machined (drilled, tapped, faced) rather than welded, at 629. "Water cooling 280" was spent — about \$200 of hose, barbs and a manifold are in the ledger — but the system was never installed: a solder-blocked joint in the upper coil made it impossible, and the magnet has run air-cooled for its whole life (builder's review, Aug 2026).

3. The as-built BOM by subsystem

The tables below are the workbook's BOM sheet, lightly edited: descriptions shortened, part numbers kept where the sheet carried one, vendor and price as recorded. "Since" notes what became of the item, from the as-built record. Prices are USD as paid.

3.1 Magnet — 5,190.64

Item	Description / part number	Vendor	USD	Since
Frame steel	1018 CR flat bar 3 × 8 in: two 28 in, two 15.5 in (quoted 2017-07-24, pickup, incl. 5.3 % tax)	Metal Supermarkets, Richmond VA	1,418.00	In service
Pole pieces	1018 round, 8 in dia × 6 in, ×2	MSC	580.22	In service
Pole extensions	1018 round, 8 in dia × 1 in, ×2	MSC	208.24	In service
Pins	1018 round, ½ in dia × 6 ft	MSC	21.20	
Shoulder screws	Alloy-steel precision shoulder screws, ×16 (ledger ×20, 135.65)	McMaster	102.95	Extension mounting
Machining	H-frame machining	BRMW	629.00	
Copper tubing	¼ in OD ACR refrigeration tube, ten 100 ft coils (ledger 471.09)	ICS	481.95	Coil 1
Copper tubing	Same, second ten coils (ledger 471.09)	ICS	481.95	Coil 2
Sleeving	Techflex Insultherm 0.263 in fiberglass sleeving, 250 ft, ×7 (ledger 798.47 in two orders)	Digi-Key	559.00	Coil insulation
Kapton tape	Polyimide adhesive tape	Amazon	22.99	Layer wrap
Cable, lugs	6 AWG welding cable, 15 ft ×2; Pico 4138C 5/16 in lugs	Amazon	38.60	Magnet leads
Power supply	Sorensen DCS55-55M62, 0–55 V / 0–55 A (surplus)	eBay	513.37	In service
Coil frame	6061 aluminum sheet 18 × 24 × 0.19 in, ×2	Midwest Steel and Aluminum	133.17	Coil forms

3.2 Chamber, lids, ports and filaments — 1,940.23

Item	Description / part number	Vendor	USD	Since
Machining	Chamber machining (ledger 1,661.00; §7)	BRMW	1,200.00	
Chamber	304/304L A-312 10 in schedule 80S pipe; the 243.02 piece prorated at one sixth	TW Metals	40.50	The 1 in slice is the chamber
Lids	304 plate 11 × 11 × 3/16 in, #2 finish (ledger: three plate orders, 226.33)	Midwest Steel and Aluminum	70.84	0.200 in lids as built
O-rings	–273 BV75 Viton 75 durometer, ×2 (ledger ×6, 34.26)	The O-Ring Store	12.56	Lid seals
Screws	UC Components FA-206-NA silver-plated 2-56	UC Components	53.71	Lid screws

Item	Description / part number	Vendor	USD	Since
Flanges	HFS weld-sock flange "KF16" — the price is the KF25 order; the KF16 dozen is under "ports"	eBay	99.90	
Epoxy	Loctite Hysol 1C (83200)	Amazon	20.28	Port bonding; no flange failures in 8 years
Dee	Lump sum (aluminum sheet, tin-snip dee)	—	30.00	Free-floating dee, never rebuilt
Ports	Lump sum (KF16 sock flanges, epoxied)	—	200.00	Ten ports
Filaments	Kimball Physics ES-020 tungsten cathode, 10-pack (second pack 213.25 in the ledger)	Kimball Physics	212.44	~20 bought, ~\$20 each

3.3 Cart and rack — 1,023.18; instrumentation — 1,338.00

Item	Description / part number	Vendor	USD	Since
Cart and rack			1,023.18	
Magnet cart	Durham HET-3048-2-95 welded 14 ga service truck, 30 × 48 in	Amazon	473.00	Magnet, pumps, H ₂ cylinder
Wood base	4×4 timbers ×5 (Home Depot, 60.00); 18-8 threaded rod ½-20 × 3 ft 98848A033 ×4 (62.48), locknuts 91831A140 ×10 (6.13), washers 90313A118 (8.66) (McMaster)		137.27	Deck under the magnet
Rack	Samson SRK21 21U universal rack stand	Amazon	249.00	The instrument rack
Rack	V7 RMBLANK1U10-1N 1U blank panels, 10-pack	Amazon	35.47	Meter and switch panels
Rack	Vented 1U cantilever shelves ×3 (eBay, 62.46); AC Infinity 2U shelves ×2 (Amazon, 65.98)		128.44	
Instrumentation			1,338.00	
Electrometer	Keithley 617 programmable electrometer (surplus)	eBay	600.00	In service; 0.1 pA floor
Oscilloscope	Siglent SDS1202X-E, 200 MHz	Amazon	379.00	XY-persistence resonance traces
Function generator	Siglent SDG1032X arbitrary waveform generator	Amazon	359.00	RF source and sweep ramp

The HT20 gaussmeter, the 4 in linear translator and the chamber feedthroughs are in service but not on the BOM sheet (§5.1).

3.4 Vacuum system — 1,023.89; hydrogen delivery — 612.22

Item	Description / part number	Vendor	USD	Since
Vacuum system			1,023.89	
Rough pump	3 cfm two-stage rotary-vane (cash purchase; not in the ledger)	Harbor Freight	149.99	Inlet re-fitted to KF16 with Hysol
Diffusion pump	Edwards SI100 (surplus)	eBay	379.00	In service; DC-704 oil
Pump oil	Dow Corning DC 704 (SPI, 66.50); Robinair 13203 (Amazon, 11.40)		77.90	
Rough-pump adapter	3/8 in BSP male × KF16 stainless adapter	eBay	20.00	
Other fittings	Lump sum (KF16/KF25 clamps, rings, blanks, tees)	—	150.00	
Gauges	Granville-Phillips 275 Mini-Convector 275806-EU (37.00); GP 354 Micro-Ion module 354001-TE-T (175.00); MKS 901P-11040 transducer (35.00) — all surplus	eBay	247.00	Foreline; chamber ports 2 and 4
Hydrogen delivery			612.22	
Gas	UHP hydrogen lecture bottle UHPHYLB (56 L)	Matheson	173.84	Replaced by a 102 L cylinder (\$5.1)
Regulator	2210 series miniature dual-stage regulator, brass, SEQ2211170F, 0–10 psig	Matheson	331.20	In service
Washers	CGA-170 Teflon washers SEQWAS0038PB, ×10	Matheson	11.50	
Needle valve	Parker 4A-NML-V-SS-K ¼ in metering valve, Swagelok ends (surplus)	eBay	53.00	Superseded by an MFC from ~Dec 2018
Tubing, fittings, mount	Tubing lump (20.00); Swagelok B-400-1-2 ×2 (11.18); 2 in PVC cylinder mount (11.50)	Amazon	42.68	

3.5 RF chain — 511.89; rack electronics — 293.27

Item	Description / part number	Vendor	USD	Since
RF chain			511.89	
Tuner	LDG AT-200PRO-II autotuner	Ham Radio Outlet	235.00	Removed from the chain, with its RBA4:1 balun (30.00, not on the BOM)

Item	Description / part number	Vendor	USD	Since
Preamp	2–80 MHz 5 W HF preamplifier	eBay	55.80	In service, 15 V rail
Power amp	2–30 MHz 50 W HF linear amplifier (IRF510 finals)	eBay	115.00	In service; a second unit (119.85) in the ledger; 10–15 FET pairs replaced
Coax, adapters	Lump sums	—	50.00	
Matching network	Ammo box (Harbor Freight, 16.00, cash); parts lump (25.00); Garolite rod ½ in × 1 ft 8526K82 (McMaster, 15.09)		56.09	Ammo-box matcher retired by 2020; the present 11-turn coil and surplus 50 pF vacuum capacitor are not costed anywhere
Rack electronics			293.27	
DC supplies	28 V 6 A(33.99, RF amp rail); 12 V 30 A (19.96, Peltier baffle, meters, formerly the autotuner); 15 V 2 A(eBay, 15.75, preamp); 24 V 2 A(11.99, gauges); 12 V 2 A(7.99)	Amazon unless noted	89.68	Four fused rails
Panel meters	DROK 0.36 in 5-digit DC voltmeters, ×3	Amazon	33.84	Gauge readouts
Switches, fuses	Jameco IG-406D-2341 keyswitch (7.75; ledger ×3); 20 ASPST and DPST rockers (26.48); 5×20 mm fuse kit (6.99)	Amazon	41.22	Switch panel
Power strip, timer	12-outlet strip with breaker (30.45); CDN TM30 timer (11.99)	Amazon	42.44	
Bench supply	30 V 3 Aadjustable	eBay	30.99	
Bias supply	Fisher Biotech FB 103 electrophoresis supply, 20–250 V (surplus)	eBay	55.10	Filament bias, alternating with battery strings over the years; in use Feb 2025 (\$5.5)



Figure 2. The instrument rack during a run on 2021-03-06 (media id IMG_2512). Top to bottom: a bench DC supply on the rack top, with the Astatic PDC2 SWR meter and a bare RF-amplifier board on the bench beside it; the Keithley 617; the DROK meter, keysw itch and rocker-sw itch panel; the Siglent SDS1202X-E with a resonance trace in XY persistence; the SDG1032X generator; the LDG AT-200PRO-II autotuner (still in the chain at this date) beside a Fisher electrophoresis supply; the Sorensen DCS 55-55 at the bottom. The HT20 gaussmeter on the bench post reads 623 mT; the CDN timer hangs at left.

4. Vendor mix

Figure 1 (right) shows the ledger by vendor; the table gives the same data with what each vendor supplied.

Vendor	Rows	Ledger USD	Share	What came from there
eBay	82	5,237.75	25.7 %	Surplus instruments, pumps, gauges, feedthroughs, KF hardware, amplifiers
Amazon	134	3,663.54	18.0 %	Cart, rack, Siglent instruments, supplies, small electrical parts
BRMW (machine shop)	2	2,290.00	11.2 %	H-frame machining 629; chamber machining 1,661
Metal Supermarkets	1	1,418.00	7.0 %	Frame steel
ICS	7	1,283.92	6.3 %	ACR copper tubing
McMaster-Carr	36	917.55	4.5 %	Fasteners, rod, Garolite, PEEK, polycarbonate, taps and bits
Digi-Key	6	885.61	4.3 %	Sleeving 798; protection diode and varistors; rack cable
MSC	4	824.49	4.0 %	Poles, pole extensions, pin stock

Vendor	Rows	Ledger USD	Share	What came from there
Matheson	6	629.59	3.1 %	Lecture bottle, regulator, CGA fittings and washers
Midwest Steel and Aluminum	4	444.58	2.2 %	Lid plate, coil-frame sheet, steel samples
Kimball Physics	2	425.69	2.1 %	Two 10-packs of ES-020 filaments
Roberts Oxygen	1	280.00	1.4 %	102 L UHP hydrogen
15 other vendors, and 16 rows with no vendor recorded	42	2,074.00	10.2 %	Cylinder fittings, lid plate, RF connectors, epoxy, tools, supplies
Total	327	20,374.72		

The sheet's own vendor subtotals agree with these to the cent for the fifteen vendors it names; its "other" bucket, 2,603.60, is everything else (Matheson, Kimball Physics, Roberts Oxygen, Ham Radio Outlet, TW Metals, Harbor Freight, UC Components, Discount Steel, Accu-Glass, Advance Auto, The O-Ring Store, MDC, and the 16 unattributed rows).

Counted by the BOM — by what is on the machine — eBay supplied 18.8 % of the as-built value (2,247), Amazon 15.7 %, the machine shop 15.3 %, the steel yard 11.9 % and the copper supplier 8.1 %.

5. Where the other \$8,441 went

Every ledger row was tagged into one of eight categories by matching descriptions to the BOM sheet and placing the rest from the as-built record; the forty largest rows were checked by hand. The categories reconcile exactly to the difference between the two sheets.

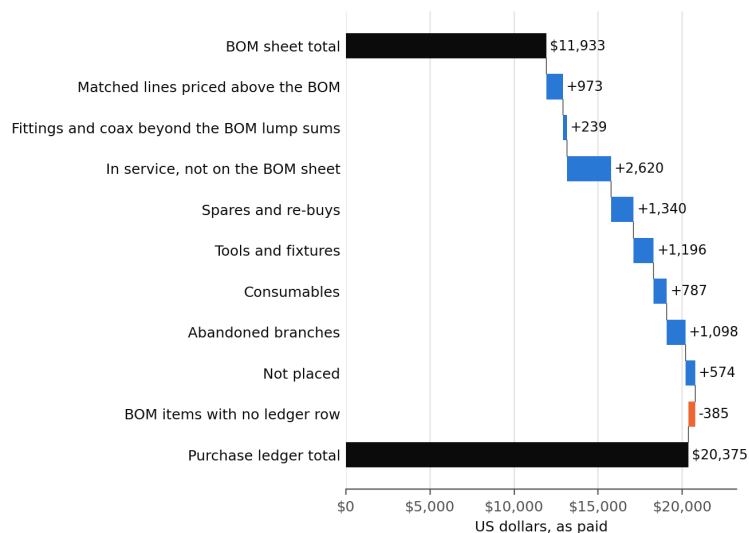


Figure 3. How the purchase ledger (20,375) exceeds the as-built BOM (11,933). Blue bars add, the orange bar subtracts; the steps sum to the 8,441 difference.

Step	USD	Rows	What it is
Matched lines priced above the BOM	+973	—	The same items at the ledger's price: chamber machining 1,661 vs 1,200; the full pipe piece 243 vs the prorated 40; sleeving 702 vs 559; a lumber receipt 200 vs 60 for the timbers; 20 shoulder screws vs 16; six O-rings vs two
Fittings and coax beyond the BOM lump sums	+239	35	KF clamps, rings, blanks, hoses, dee sheet, coax and RF adapters: 730 in the ledger against 491 of BOM lump sums (ports 200, other fittings 150, coax 30, adapters 20, matching network 25 + 16 ammo box, dee 30, tubing 20)
In service, not on the BOM sheet	+2,620	74	§5.1
Spares and re-buys	+1,340	21	§5.2
Tools and fixtures	+1,196	40	§5.3
Consumables	+787	42	Solder and flux, isopropyl, wipes, gloves, pump oil, epoxy refills, bias batteries, hardware assortments
Abandoned branches	+1,098	27	§5.4
Not placed	+574	23	§5.6
BOM items with no ledger row	−385	—	The rough pump (149.99), a cash purchase the ledger never recorded, and the autotuner (235), whose ledger row is counted under abandoned branches
Difference	+8,441		

5.1 In service but not on the BOM sheet — 2,620

The largest explanation. The BOM sheet was kept during the build and not updated afterwards; the hardware below is on the machine today according to the as-built record.

USD	Item	Where it is
393.05	102 L UHP hydrogen cylinder (Roberts Oxygen, 280.00) with CGA-350 stainless fittings and washers (Matheson)	Gas supply since the MFC era; the BOM still shows the 56 L lecture bottle
287.80	4-pin KF16 feedthrough with cable (242.80) and 4-pin ceramic feedthrough (45.00)	Chamber ports 7 and 9 (filament + pickup; Faraday cup)
125.00	KF25 2 kV single-pole feedthrough	Port 6, dee RF feed, adapted to SO-239
37.00	KF16 BNC feedthrough	Port 9, Faraday-cup signal
150.00	Huntington VF-107 4 in linear translator	Port 10, Faraday-cup radius

USD	Item	Where it is
110.88	HT20 Hall gaussmeter	The field instrument
286.26	ISO100→ISO63 adapter flange (141.99), ISO63 blank, seals and claw clamps	SI100 inlet; the adapter's KF25 side port is the vacuum path
50.00	KF25 300 mm bellows hose	Diff pump to chamber port 1
261.80	Foreline and adapters: KF16 flex hose, elbow, tee, VAT isolation valve, vent valve, KF16 cross, KF25–KF16 reducers, NPT adapter	
105.36	3/16 in ACR tubing, two orders	RF matching coils
159.52	Kapton-insulated vacuum wire (59.64), alumina sheet and tube (54.02), FA-204-SV vented dee screws (45.86)	In-vacuum wiring, ion-source insulator, dee
84.84	Astatic PDC2 SWR meter, RF sampler, 1 dB N attenuator	RF chain monitoring
150.70	Coil ties (63.56), 22 AWG rack cable (62.30), flyback diode and varistors (24.84)	Coils, rack, magnet-supply protection
417.69	The remaining 34 rows: DB9/DB15 cables and breakouts, terminal strips, relays, fuse holders, a panel meter and LED, two more 1U shelves, thermocouples and wire, magnet-assembly rod, eyebolt and Grade 8 bolts, H ₂ -line Swagelok and A-Lok fittings, a second rough-pump adapter, viewport glass, the foreline trap	

5.2 Spares and re-buys — 1,340

A second 10-pack of filaments (213.25; about twenty bought in all, spares remain plus tungsten wire to make more); a second 50 W amplifier (119.85 — the IRF510 finals failed repeatedly under mismatch, and the FETs were replaced far more often than the amplifier); two further 2-coil orders of ¼ in ACR tubing (203.14) and a Grainger coil (77.95) beyond the 18 coils the magnet used; the first, small sleeving order (96.09); second and third lid-plate orders (155.49 — lid material was bought three times); a second bottle of DC-704 (71.50); 15 extra KF16 weld-sock flanges, a second KF16 cross, vent valve and ISO63 blank, and an alternative rough-pump adapter (271.87); a second set of three 1U shelves (62.46); two extra keyswitches, 5/16 in coupler stock and a second rod size for the pins (68.33).

5.3 Tools and fixtures — 1,196

Not part of the machine, but bought for it: a 2-ton shop crane (170) and a 660 lb magnetic lifter (96) for handling the iron; a CDI micro-adjustable torque driver (144) for the 2-56 lid screws; the first hardware-store run of saw horses and wrenches (102); polycarbonate sheet in four thicknesses (167) for the simulated-chamber capacitor on which the RF match was developed; a 100 W dummy load (32); three laboratory jacks (78); 2-56 taps, hex bits, a hole saw, wire-gauge-50 drill bits and a Silver-and-Deming set (193); crimpers, a label maker and tapes, a turns counter and clamps for the winding stand, a rope hoist, feeler gauges and a pole detector. The 3-D printed models, the CAD work and the home-made rough-pump exhaust filter are not costed anywhere.

5.4 Abandoned branches — 1,098

USD	Branch	Outcome
265.00	LDGAT-200PRO-II autotuner and RBA4:1 balun	In the chain 2018 to about 2021; removed. The BOM still carries the tuner
199.37	Coil water cooling: silicone and RO tubing, hose barbs, a 1/8 in NPT manifold	Never installed; the magnet is permanently air-cooled
164.71	Steel sample pieces (1/8 × 3, 3 × 8 × 6.5, 3 × 3 × 1/4)	Test pieces bought before the frame steel
164.62	BriskHeat 1 in × 120 in silicone heat tape	Bakeout was a learning-era practice only; the chamber is not baked
93.05	Two ISO100 aluminum blanks	The SI100 inlet took an adapter flange instead
75.00	Sixteen ISO320-500 double-claw clamps	No flange of that size on the machine
42.28	Four -377 Viton O-rings (10 in ID)	From the earlier -377 gland design; the final gland takes -273
31.62	Pneumatic solenoid valve and push-in fittings	The air-actuated diff-pump valve of the 2018 procedures, replaced by hand valves
28.96	Fourteen CF 1.33 in copper gaskets	No CF flanges on the machine
26.41	8 in schedule 40 stainless pipe, 1 in	From the 8 in chamber concept that preceded the 10 in pipe

5.5 On the machine, in neither sheet

The UNIT UFC-1101 mass-flow controller (about December 2018) and the Horiba/STEC SEC-7320M 1 sccm controller that replaced it (calibrated 2021-05-15); the 50 pF glass vacuum capacitor and 11-turn coil of the present matching network; the LMR-400 coax to the chamber; the diffusion-pump supply box (variac, 12 V Peltier supply, fan); and the viewport's 1/4 in borosilicate disc, unless the 1 in BK7 disc in the ledger (14.99) is it. Their cost is not recorded.

The Fisher FB 103 bias supply is a puzzle the other way. It is on the BOM and in the ledger at 55.10 among the rack-electronics purchases; the workbook's hydrogen sheet lists it among bias-supply candidates at 60; a supply of that pattern is visible in the rack in March 2021 (Figure 2); and the builder's 2026 recollection is that it was bought after the 9 V bias batteries all died on 2025-02-01. The simplest reading is that it was bought early with the rack electronics and pressed into filament-bias service in 2025. The builder's September 2026 note settles it: the FB 103 has been used for filament bias on and off for years, alternating with battery strings, so the ledger's early position is right and the "2025 purchase" recollection refers to its return to service.

5.6 Not placed — 574

Twenty-three rows the record does not explain: two PEEK bars (106), aluminum bolt-together framing with rod, nuts and washers (103), four stainless trays (37), 10 in and 8 in aluminum pipe

sections (116; chamber studies or winding forms), 1008 sheet and small 1018 bar from Stockcar Steel (115; shims or the proof-of-concept mini-magnet), a 10 ft length of 1¼ in galvanized pipe (30), a 100 A two-pole knife switch (27), a Dell 1,570 W server power supply (30) and a foot of 5/8 in copper tube (10). None affects the machine's account materially; they are listed so the classification is complete.

6. Used versus new

The instruments and vacuum hardware that would dominate a new-equipment budget were bought surplus. The machine-critical eBay purchases:

USD	Item	On the machine
600.00	Keithley 617 electrometer	Yes
513.37	Sorensen DCS55-55M62 magnet supply	Yes
379.00	Edwards SI100 diffusion pump	Yes
242.80 + 45.00	Two 4-pin KF16 feedthroughs	Yes
175.00 + 37.00 + 35.00	GP-354 Micro-Ion, GP-275 Convector, MKS 901P	Yes
150.00	Huntington VF-107 linear translator	Yes
141.99	ISO100/ISO63 adapter flange	Yes
125.00	KF25 2 kV feedthrough	Yes
115.00 + 119.85	Two 50 W HF amplifiers	One
110.88	HT20 gaussmeter	Yes
55.80	5 W HF preamplifier	Yes
55.10	Fisher FB 103 supply	Yes
164.62	BriskHeat heat tape	No

The four items at the top — electrometer, magnet supply, diffusion pump, ion gauge — cost 1,667 together; the two bench instruments bought new, the Siglent oscilloscope and generator, cost 738. The KF16/KF25/ISO flanges, clamps, rings, blanks, hoses and valves came almost entirely from eBay as well, at 8 to 60 dollars a line. Bought new or made to order: the frame steel (1,418, local yard, picked up), the poles and extensions (788, MSC), the copper (1,284, ICS), the sleeving (798, Digi-Key), the filaments (426, Kimball Physics), the regulator and gas fittings (630, Matheson), the cart (473) and rack (413).

The machine-shop lines, as the two sheets carry them:

Job	Vendor	BOM	Ledger
H-frame machining	BRMW	629	629
Chamber machining	BRMW	1,200	1,661

Job	Vendor	BOM	Ledger
Total		1,829 (15.3 % of the BOM)	2,290 (11.2 % of the ledger)

These are facts of the record; whether the shop work could have been done in-house, or the surplus items replaced by new ones, is a question for a later note.

7. Sources and their disagreements

Point	BOM sheet	Ledger or other primary source	Reading
Chamber machining	1,200	1,661 (BRMV)	The ledger is the payment record; the BOM may carry a quote
Frame steel	1,418	Metal Supermarkets quote of 2017-07-24: 1,346.33 + 5.3 % tax = 1,417.69, pickup	Agree. The workbook's iron sheet also carries an earlier online quote of 1,029.76 including 277.80 shipping, which was not the purchase; earlier internal documentation repeated that figure
Sleeving	559 (×7)	96.09 + 702.38	The BOM understates by 239
Chamber pipe; lid plate; shoulder screws; O-rings	40.50; 70.84; 102.95 (×16); 12.56 (×2)	243.02; three orders 226.33; 135.65 (×20); 34.26 (×6)	Proration and quantity, leftovers are on hand
Flanges line	"KF16 weld-sock flange", 99.90	99.90 is the KF25 order; the KF16 dozen cost 119.88	Description and price crossed
Rough pump; ammo box	149.99; 16.00	Not in the ledger	Cash purchases at Harbor Freight
Copper tubing orders	481.95 ×2	471.09 ×2	Probably shipping recorded on one sheet only
Autotuner; hydrogen supply	Tuner listed, 235; 56 L lecture bottle	Tuner removed; 102 L cylinder installed	The BOM was not revised when the machine changed
FB 103 supply	55.10	55.10; hydrogen sheet 60; visible in a 2021 photo; used on and off for years (builder, Sept 2026)	\$5.5

8. What it would cost today

Nothing here has been re-priced. The figures are US dollars as paid between 2017 and 2021, mostly on eBay and Amazon, with tax and shipping recorded inconsistently. Three of the four largest items

were one-off surplus finds whose prices are not reproducible on demand; the steel, copper and machine-shop lines are commodity- and labor-priced and have moved since 2017; and the ledger omits a few items now on the machine (\$5.5). A reader budgeting a similar build should treat the BOM total as a lower bound on what the machine contains, the ledger total as what a first build of this kind actually consumed, false starts included, and expect both to be higher in current dollars.

Sources

- Design workbook `cyclotron9.xlsx`, sheets budget, BOM, purchases, iron, cart, rack, vacuum, RF, H2.
- Metal Supermarkets (Richmond, VA) quote, 24 July 2017.
- The Mark I as-built documentation suite (magnet, chamber and ports, vacuum, RF and dee, gas and ion source, instrumentation, power and rack), incorporating the builder's review of August 2026.
- The run log `cyclotron_log.xlsx` (dating of the MFC era, amplifier failures, the 2025 battery failure).
- The build website, `mullinscyclotron.weebly.com`.
- Photo record, media id `IMG_2512` (2021-03-06).
- Classification script and per-row table, `bom-cost_classify.py` and `bom-cost_classified.csv`, published with this note's figures.

Open items

- The ledger carries no purchase dates; receipts would date the 327 rows and settle the FB 103 question.
- The two mass-flow controllers, the vacuum capacitor, the LMR-400 feed and the diffusion-pump supply box have no recorded cost.
- Twenty-three ledger rows (574) are not placed; the builder may recognize most of them.
- The BOM sheet has not been revised since the build; a revised as-built BOM would add the \$5.1 items and drop the autotuner and the lecture bottle.