Title
COMPARATIVE SPECIFICATIONS - RADIATION LABORATORY ACCELERATORS

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COMPARATIVE SPECIFICATIONS
UNCLASSIFIED

Radiation Laboratory
ACCELERATORS

60-Inch Cyclotron
184-Inch Synchrocyclotron
Synchrotron
Bevatron
4-Mev Van De Graaff
40-Ft. Linear Accelerator

UNIVERSITY OF CALIFORNIA
Berkeley, California

OCTOBER 1951
60-INCH CYCLOTRON

PERFORMANCE: Beam particle & beam energy (max.)
- Beam particle & beam energy (max.)
  - Protons (from H₂)
    - 10 Mev
  - Deuterons
    - 20 Mev
  - Alpha particles
    - 40 Mev
- Beam intensity - average current
  - Protons
    - 30 μ amps
  - Deuterons
    - 40 μ amps
  - Alpha particles
    - 10 μ amps
- Beam intensity - peak current
  - Protons
    - 50 μ amps
  - Deuterons
    - 70 μ amps
  - Alpha particles
    - 25 μ amps
- Time required for acceleration
  - Protons
    - 6.8 μ secs
  - Deuterons
    - 6.8 μ secs
  - Alpha particles
    - 6.8 μ secs
- No. of revolutions during acceleration
  - Protons
    - 80
  - Deuterons
    - 80
  - Alpha particles
    - 80
- Distance traveled during acceleration
  - Protons
    - 1 mile
  - Deuterons
    - 1 mile
  - Alpha particles
    - 1 mile
- Velocity of maximum energy \( \beta = \frac{v}{c} \)
  - Protons
    - 0.14 or 26,000 miles/sec.
  - Deuterons
    - 0.20 inches
  - Alpha particles
    - 0.02 inches
- Range of full energy particles
  - Protons
    - 0.02 inches
  - Deuterons
    - 0.04 inches
  - Alpha particles
    - 0.02 inches
- Shielding required
  - Water-5' thick sides, 4' thick top-to be increased
- Mass increase at maximum energy (% Rest mass)
  - Protons
    - 1%
  - Deuterons
    - 1%
  - Alpha particles
    - 1%

MAGNET

- Pole tip diameter
  - 72"
- Pole maximum diameter
  - 72"
- Pole Gap-nominal
  - 11 1/2"
- Magnetic field (center)
  - 15,000 gauss
- Weight - steel
  - 194 tons
- Copper coils
  - 25.5 tons
- Number of turns - total
  - 1,482
- Ampere turns
  - 414,000
- Power to magnet: amps, volts, & kw
  - 280 amps, 270 volts, 76 kw
- Coil cooling means
  - oil

OSCILLATOR

- Power input
  - 75 - 90 kw
- Oscillator tube(s)
  - 1 Backus-Webb special triode
- Frequency
  - 11.56 mc (deuterons)
- Number of dees
  - 2
- Dee voltage
  - 80-90 kv (175 kv accel. voltage)
- R. F. System
  - grounded grid circuit
- Capacitance *(for constant current network)
  - 5040 mfd at 440 volts
- Rotary capacitor

OTHER

- Vacuum pumps
  - 6-4" oil diffusion, 2-14" oil diffusion
- Operating vacuum
  - 2 x 10⁻⁵ mm. Hg
- Volume acceleration chamber
  - 141 cu. ft.
- Equivalent volume at sea level pressure
  - 0.1 cu. cm. (Pea)

DEFLECTOR

- Deflector and exit radii
  - 30.3", 25.1"
- Angular length
  - 60°
- Operating voltage
  - 40 kv dc

BUILDING

- Room dimensions
  - 60' x 60' x 20' high
- Crane
  - 1 ton

HISTORY

- Design started
  - October 1936
- Construction started
  - January 1938
- First operation
  - June 1939
- Rebuilt
  - July 1944 & November 1949
### 184-INCH SYNCHROCYCLOTRON

#### PROTONS
- **350 Mev**
- **0.75 μ amps**
- **120 μ amps**
- **1,900 μ secs**
- **37,000 miles**
- **0.69 or 128,000 miles/sec**
- **12.25 inches**
- **Concrete - 15' thick on sides, 4' thick on top - to be increased**
- **37.4%**

#### DEUTERONS
- **195 Mev**
- **0.75 μ amps**
- **120 μ amps**
- **2,400 μ secs**
- **25,000 miles**
- **0.43 or 80,000 miles/sec**
- **2.75 inches**
- **15,000 gauss**

#### ALPHA PARTICLES
- **390 Mev**
- **0.1 μ amps**
- **16 μ amps**
- **2,400 μ secs**
- **25,000 miles**
- **0.43 or 80,000 miles/sec**
- **1.37 inches**

#### (Data in this column applies to all operation of Cyclotron unless otherwise noted)
- **182**
- **184**
- **23"**
- **56 kw peak, 8.5 kw avg.**
- **84 kw peak, 21 kw avg.**
- **84 kw peak, 21 kw avg.**
- **22.9 to 15.8 mc**
- **11.5 to 9.8 mc**
- **17 kv**
- **12 kv**

For frequency modulation - 100-2,500 μμ fd; speed-600 rpm: 6 blades, 72 teeth each; nominal gap 1/8 inch; weight - 1 ton; pulse rate - 60 per second.

**2-32" oil diffusion; 1-750 cfm, 1-250 cfm, 2-105 cfm Kinneys**
- **2.5 x 10^-5 mm. Hg.**
- **1.909 cu. ft.**
- **0.177 cu. cm. (Pea)**

**Electrostatic and magnetic**
- **Electrostatic: 82": magnetic: 83 1/2"**
- **Electrostatic: ~ 120 °**
- **250 kv pulsed**

- **160' diameter, 90' high**
- **Radial, 30 ton, 77' span overhead**
SYNCHROTRON

PERFORMANCE: Beam particle & beam energy (max.)

<table>
<thead>
<tr>
<th>Beam particle</th>
<th>beam energy (max.)</th>
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<tbody>
<tr>
<td>Electrons</td>
<td>2 Mev</td>
</tr>
</tbody>
</table>

Time required for accel.         100 \( \mu \) sec.
No. of rev. during accel.         3,800
Distance traveled during accel.   15 Miles
Velocity at max. energy \((\beta = \frac{v}{c})\) 0.98 or 182,000 miles/sec.
Max. magnetic field - gauss       8.2

ACCELERATION CHAMBER

Radius at center                   39 3/8 in.
Straight sections - length         -
Length of orbit                     -
Aperture                           20.5 ft.
Volume-and equivalent volume       2-5/8 x 5-3/8 in.
At sea level pressure              1.6 cu. ft.

MAGNET

Pole diameter                      90 in.
Pole gap                            3.7 in.
Weight - iron                       135 tons
- copper                            1-3/4 tons
No. of turns                        32
Length of coil                      854 ft.
Ampere turns - max.                90,000
Cooling means                       Air
Peak instantaneous current, voltage
to magnet                           2,800 amps., 19,000 volts

Peak power to magnet               26,600 kVA
Reactive power                     62 kw
Power required - average           6/sec.
Repetition rate                    145,000 joules
Energy stored                      805 mfd
Total capacitance                  1/30 sec.
Magnet pulse duration              -

INJECTION

Injection energy                   100 kv

OSCIILLATOR & RF ACCELERATION

Power input                        10 kw
Frequency - min. - max. (normal)   44.6-50.4 (47.7) mc/sec.
Frequency ratio                    (constant)
RF voltage across accel. gap (max.) 3.5 kv
Vacuum pumps                       2-6" oil diffusion: 1-105,
Operating vacuum                   2-11 cfm Kinneys
                                    5 x 10^{-6} mm. Hg

BUILDING

Accelerator room dimensions        30' x 50'
Crane size                         70 tons

HISTORY

Design started                      October 1945
Construction started                October 1946
First Operation                     December 16, 1948
BEVATRON

FIRST PHASE

Protons
3.65 Bev

1.75 sec.
3,800,000
270,000 miles
0.937 or 184,000 miles/sec.
9,800

582 in.
20 ft.
385 ft.
2 x 6 ft.
14,000 cu. ft.
6 cc's (Marble)

120 ft. (Approx.)
25 in.
9,700 tons
347 tons
88
137,500 ft.
733,000
Air
8,333 Amps., 18,000 volts

100,000 kw
3,500 kw
10/min.
83 megajoules
3 sec.

10 Mev

25 kw (est.)
0.37-2.5 mc/sec.
6.7
12.4 kv
24-32" oil diffusion
$10^{-5}$ mm. Hg

SECOND PHASE

Protons
6.44 Bev

1.85 sec.
4,100,000
305,000 miles
0.992 or 185,000 miles/sec.
16,000

600 in.
20 ft.
394 ft.
1 x 4 ft.
8,000 cu. ft.
3 cc's (Marble)

120 ft. (Approx.)
13 in.
9,700 tons
347 tons
88
137,500 ft.
733,000
Air
8,333 Amps., 18,000 volts

100,000 kw
3,500 kw
10/min.
80 megajoules
4 sec.

10 Mev

25 kw (est.)
0.36-2.46 mc/sec.
6.3
22 kv
24-32" oil diffusion
$10^{-5}$ mm. Hg

220 ft. diameter
69 ft. high
2-radial, 30 ton

February 1948
September 1949
4 MEV VAN DE GRAAFF ELECTROSTATIC GENERATOR

PERFORMANCE:

- Beam particle and energy: normal
- Beam intensity (pulsed): normal peak
- Beam diameter (approx.):
- Total kva input:
- Pulse length; repetition rate (normal):
- Corona current (approx.):
- Range of normal energy particles (in. of aluminum):
- Protons - 4.0 Mev
- Protons - 4.7 Mev
- 1.5 milliamps
- 40 µ amps
- < 1/10 inch
- 32 kva
- 500 µ sec.; 15 pulsed/sec.
- 100 µ amps
- 0.005 inches

TANK, ETC.

- Dimensions & volume: (steel) 8 ft. diam., 27 ft. long, 1 inch thick; 1,300 cu. ft.
- Weight: 20 tons
- Pressure: 100 - 120 psi
- Insulating gas: nitrogen and freon
- Charging belt (medium 4 ply cotton): 439 in. long, 20 in. wide
- Tension and speed: 800 lbs., 88 ft./sec.
- Drive: 15 hp.
- High voltage shell diameter; length: 56 in. diam.; 73 in. long
- Intermediate shell diameter: 76 in. diameter
- Texolite high voltage shell support tubes: 6
- Acceleration tube length; inside diameter: 176 in. long; 3 in. I.D.
- Insulated sections; potential gradient: 68; 60 kv
- Operating pressure (Vacuum): 2 x 10^-5 mm. Hg

OPERATION

- Voltage & current available:
  - Ion extractor probe: 20 kv., 1 ma
  - Focusing electrode: 10 kv., 1 ma
  - Accelerating electrode: 60 kv., 5 ma
  - Belt spray supply: 60 kv., 3 ma
  - Ion source: 1.5 milliamps protons
  - Control-modulated light beam
  - Transmission tube-Sylvania
  - Receiving tube-RCA

PROTON SUPPLY

- Hydrogen tank in high voltage shell. Palladium leak feeds hydrogen to Gow source and then to beam. Excess gas is drawn off and pumped back into hydrogen supply.

- Cooling of equipment in high voltage shell by air blown through Texolite support tube.

HISTORY

- Design started: November 1945
- Construction started: February 1946
- First operation: July 17, 1947
- Rebuilt: March 1951
40-FOOT LINEAR ACCELERATOR

PERFORMANCE:

Beam particle and energy
- Protons - 32 Mev output (4 Mev input)
- Maximum beam intensity (pulsed) peak; average: 16 μ amps; 0.25 μ amps
- Normal beam intensity (pulsed) peak; average: 12 μ amps; 0.08 μ amps
- Beam diameter (approximate): < 1/10 inch
- Angular divergence of beam: ± 0.001 radian
- Energy spread of beam: < 0.3%
- Range of full energy particles (in. of aluminum): 0.19 inches

TANK, ETC.

Dimensions & volume:

Steel vacuum tank: 1/2" x 49" diam., 41 ft. long, 535 cu. ft.
Copper liner, aluminum frame: 38 1/4" diam., 40 ft. long, 318 cu. ft.

Weight - total: 8 tons
Steel tank: ~ 15,000 lbs.
Copper and aluminum liner: ~ 1,200 lbs.
Vacuum - operating: 1.2 x 10^5 mm. Hg
Vacuum pumps: 1-30" oil diffusion, 2-43 cfm Kinneys
Cooling means: Water, 28 gal. per minute
Drift tubes:
Number: 47
Dimensions: 4.4-10.9 in. long; 2.7-4.7 in. diameter
Ratio gap length to drift tube length: ~ 0.2 (#1) - 0.25 (#47)

OPERATION

Operating frequency: 203 mc per sec.
Magnetic field, edge of tank: 51 gauss
Skin current: 13,000 amps, peak
Peak kva in tank: 147 x 10^6 kva
"Q" - theoretical: 70,000
- experimental: 58,000
R. F. energy storage: 116 joules
Wall and drift tube losses: 2.1 megawatts
% Total loss in drift tubes: 40%

BUILDING

Room area used (inc. Van de Graaff generator): 50' x 100' approx.
Crane size: 2 ton

HISTORY

Design started: November 1945
Construction started: June 1946
First operation: November 18, 1947
New oscillator system: March 1951