Low-Melting-Temperature Metals for Possible Use as Primary Targets at a Muon Collider Source

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http://www.hep.princeton/mumu/target/

Why a Liquid Target?

Destructive heating of solid targets by primary beam of $\approx 10^{14}$ protons/pulse.

$\Rightarrow$ Jet of liquid high-Z metal.

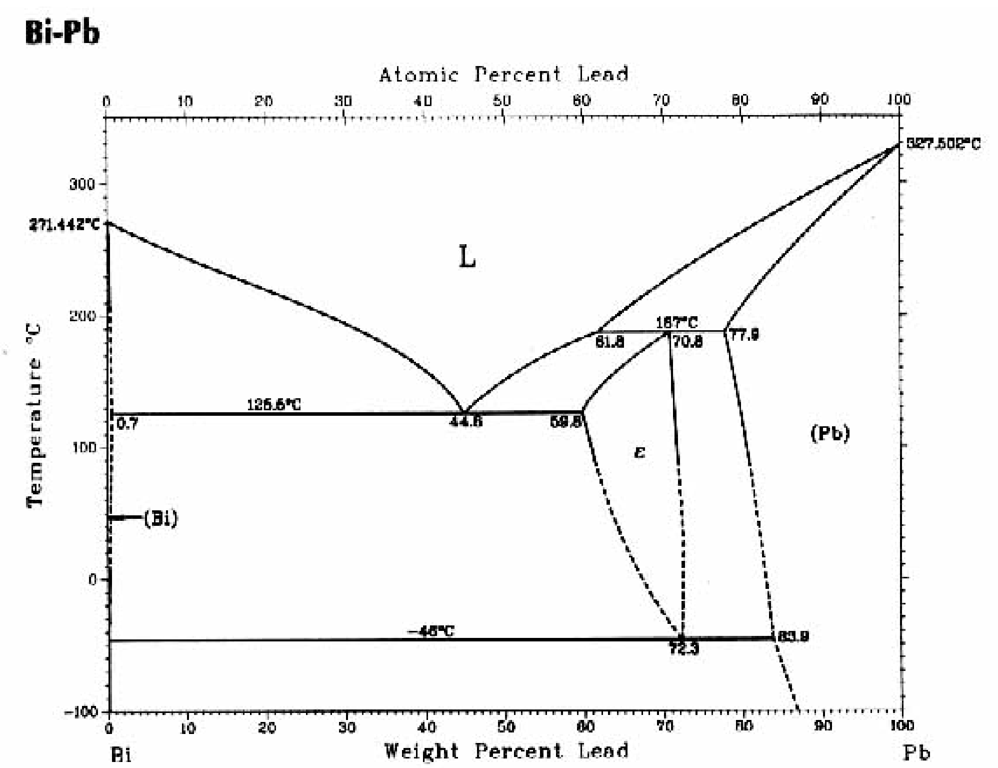
Metal should solidify at room temp. in case of 'incident'.

Mercury: toxic vapors; room-temp. liquid.

$\Rightarrow$ Consider low-melting-temperature metals.

Problems: Eddy currents; boiling.

Element	Atomic Number	Density (gm/cm^3)	Melting Temp. (°C)	Boiling Temp. (°C)	Heat Capacity (J/gm-°C)	Heat of Vapor. (J/gm)	Thermal Cond. (W/cm)
Bismuth	83	9.7	271	1610	0.12	501	0.079
Cadmium	48	8.6	321	767	0.23	886	0.97
Gallium	31	5.9	30	2403	0.37	3712	0.48
Indium	49	7.3	156	2073	0.23	2016	0.82
Lead	82	11.35	327	1750	0.13	858	0.35
Mercury	80	13.5	−39	357	0.14	295	0.083
Tin	50	6-7	232	2603	0.23	2487	0.67



Minimum melting temperature = 125.5°C.

Will a Strong Magnetic Field Repel a Metal Jet?

Ring of radius r, radial extent Δr, and thickness t.

$v \parallel B$

Flux: $\Phi = \pi r^2 B$, so $\dot{\Phi} = \pi r^2 \dot{B} = \pi r^2 B' v$.

$$\text{Resistance of ring:} \qquad R = \frac{2\pi r}{\sigma t \Delta r}.$$

$$\text{Induced current:} \qquad I = \frac{\mathcal{E}}{R} = \frac{\dot{\Phi}}{R} = \frac{\sigma r t B' v \Delta r}{2}.$$

$$\text{Lorentz force:} \qquad \Delta F = -2\pi r B I = -\pi \sigma r^2 t B B' v \Delta r.$$

Integrate over radius r : $$F = -\frac{\pi \sigma r^3 t (B^2)' v}{6} = m\dot{v} = \pi \rho r^2 t v' v,$$

$$v = v_0 - \frac{\sigma r B^2}{6\rho}, \qquad \text{where } v_0 = \text{ velocity outside field.}$$

Minimum Velocity to Penetrate Field

$$v_0 > \frac{\sigma r B^2}{6\rho}.$$

Alloys 136 and 255 have conductivity $\approx 2\%$ of Cu,

$\Rightarrow \sigma \approx 10^6$ MKS units.

$$v_0 \approx 40 \text{ m/s} \left[\frac{r}{1 \text{ mm}}\right] \left[\frac{B}{50 \text{ T}}\right]^2.$$

Fairly large jet velocities will be required to penetrate the solenoid!

Measurement of Alloy Conductivities as Liquids

Used 30-cm-long capillary tube in oven.

$\sigma_{136} = 1.35 \times 10^6$ MKS units for alloy 136,

$\sigma_{255} = 1.31 \times 10^6$ MKS units for alloy 255.

Similar to conductivities of solid state.

Will the Beam Heating Boil the Liquid Target?

Wouldn't affect targeting: $\Delta t_{\rm beam} \approx 1$ nsec,

$\Delta t_{\rm boil} \approx r/v_{\rm sound} \approx 10\ \mu$sec.

Fig. 4.13, p. 186 of the 1996 Muon Collider Feasibility Study:

50 J deposited in 1 λ_0 Hg target by 10^{14} 30-GeV protons.

λ_0(Hg) $\approx$ 115 g/cm, $\Rightarrow$ 0.43 J-cm^2/gm.

$$\Rightarrow \frac{0.14}{[r/1\ {\rm cm}]^2}\ {\rm J/gm}.$$

Boiling point of bismuth alloys $\approx$ 1600°C.

Specific heat $\approx$ 0.13 J/gm.

$\Rightarrow$ 200 J for $\Delta T = 1500$°C.

$\Rightarrow$ no boiling for $r > 0.025$ cm.