Cryocooling in the 21st Century

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4K is routine

Today’s cryocoolers can routinely cool from room temperature to 4K or less within ~90 mins of being switched on.

How many Watts of cooling are required?

Stefan–Boltzmann law: \( \text{Heat Energy} = \varepsilon \sigma T^4 \)

1W at 4.2K (LHe temp) together with 100W at 77K (LN\(_2\) temp)
Early MRI
Dealing With Liquid Cryogens in Magnets & Early MRI
Run Hours & Service Intervention

**CAR ~ 6 years**
- 60,000 miles
- 1500 hours
- 6 Services

**Cryocooler**
- 6 years
- 50,000 hours
- 2~3 Services

**Domestic Fridge**
- 6 years
- 50,000 hours
- 0 Services
Cryocooler Applications

10K GM Shield Cooler for MRI & Research Magnets

- Cold Head
- Turret
- Outer Vacuum Container ~300K
- 80K Shield
- 20K Shield
- LHe Vessel & Magnet
Cryocooler Applications

10K GM Shield Cooler for MRI & Research Magnets

In Helium

Outer Vacuum Container

80K Shield

20K Shield

In Vacuum Sleeve
Cryocooler Applications

4K GM Recondensor for MRI & Research Magnets

Direct Couple to Dry Magnet

Outer Vacuum Container

80K Shield

In Vacuum Sleeve
Global Cryocooler Market Growth Drivers

• Cost & Convenience
  – Availability and cost of Helium
  – Conservation of Helium
  – Convenience
  – Health and Safety
  – Reduction of Operating Costs
  – Simplification of System design and Build
  – Reduction of system cost
Energy

- Cryocoolers have low thermodynamic efficiency (typically 1% or so)
- Therefore the main downside to the use of cryocoolers is the electrical requirement which in many devices is in the range of some kW.
- Cryocoolers do enable designs which save energy or material in other parts of the system.
- A full calculation to compare to the energy consumed to produce and transfer liquid cryogens to the point of use, keep them topped up etc is complex.
- Reduction of energy consumption is a worthy future goal for cryocooler development and some systems are already coming to market with this in mind

  e.g. Sicera Cryopump
The Future: Emerging Markets
BRICS(M) & VISTA

• **BRICS**: Brazil, Russia, India, and China
  - These countries account for over 25% of the world's land coverage and 40% of the world's population.
  - Mexico and South Korea (sometimes added but not originally included because already more developed).

• **VISTA**: Vietnam, Indonesia, South Africa, Turkey, Argentina.

• Next Eleven (or N-11) are eleven countries—Bangladesh, Egypt, Indonesia, Iran, Mexico, Nigeria, Pakistan, the Philippines, South Korea, Turkey, and Vietnam

**Strong Position for UK Cryogenic Manufacturers /Exporters**

1. **High Expertise & Experience**
2. **Low Pound**
3. **Business Language for International Collaboration**
GDP Growth Rate Comparisons
Undulator magnets used in a storage ring to convert the electron-beam’s energy into various electromagnetic radiation frequencies by creating a magnetic field of alternating polarity through which the free electrons are passed, causing them to "wiggle" and release radiation. Also known as a wiggler, these magnets enhance the output intensity by many orders of magnitude at e.g. Soleil in France or Diamond in UK.
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