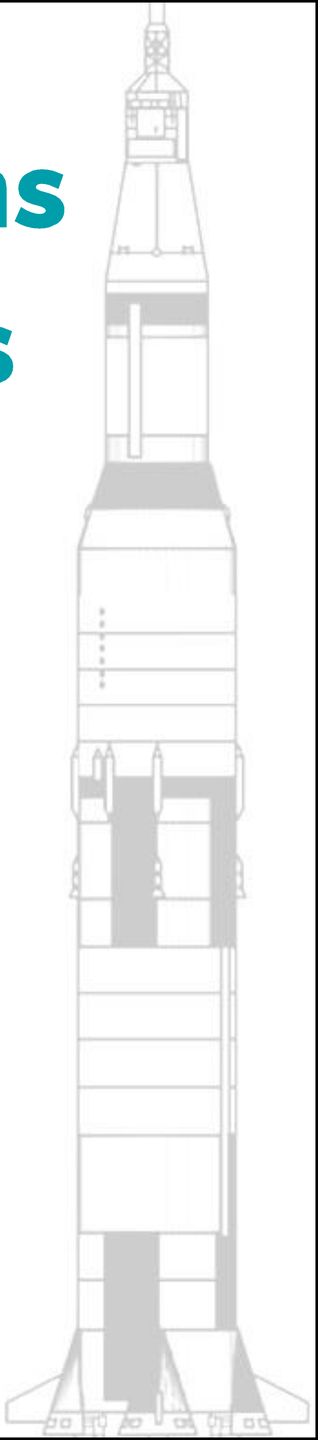
Lubrication Considerations for Extreme Environments



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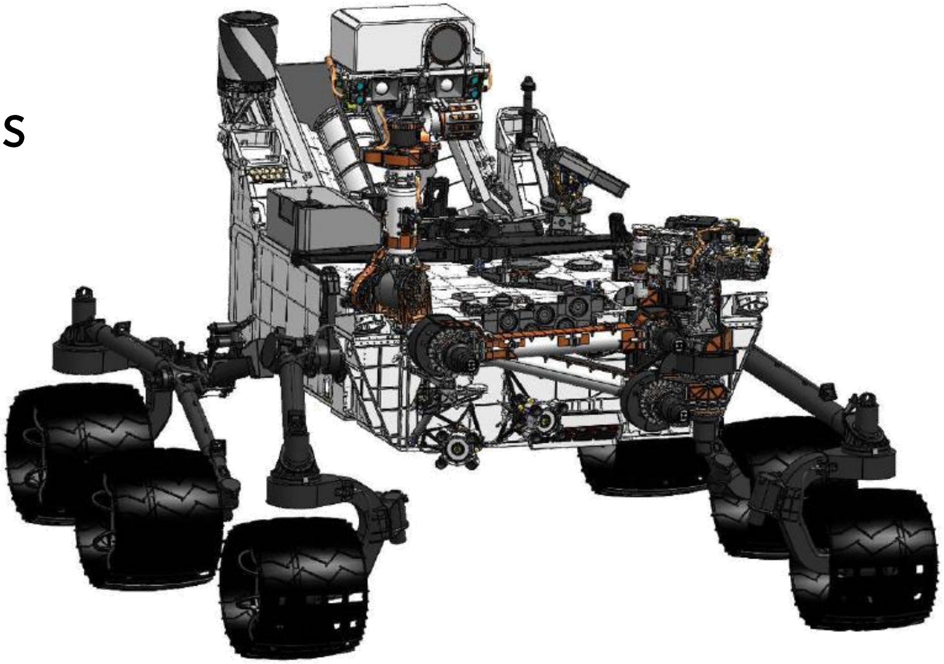
Topics

- Welcome
- Extreme Temperatures
- Extreme Pressures
- In Vivo Environments



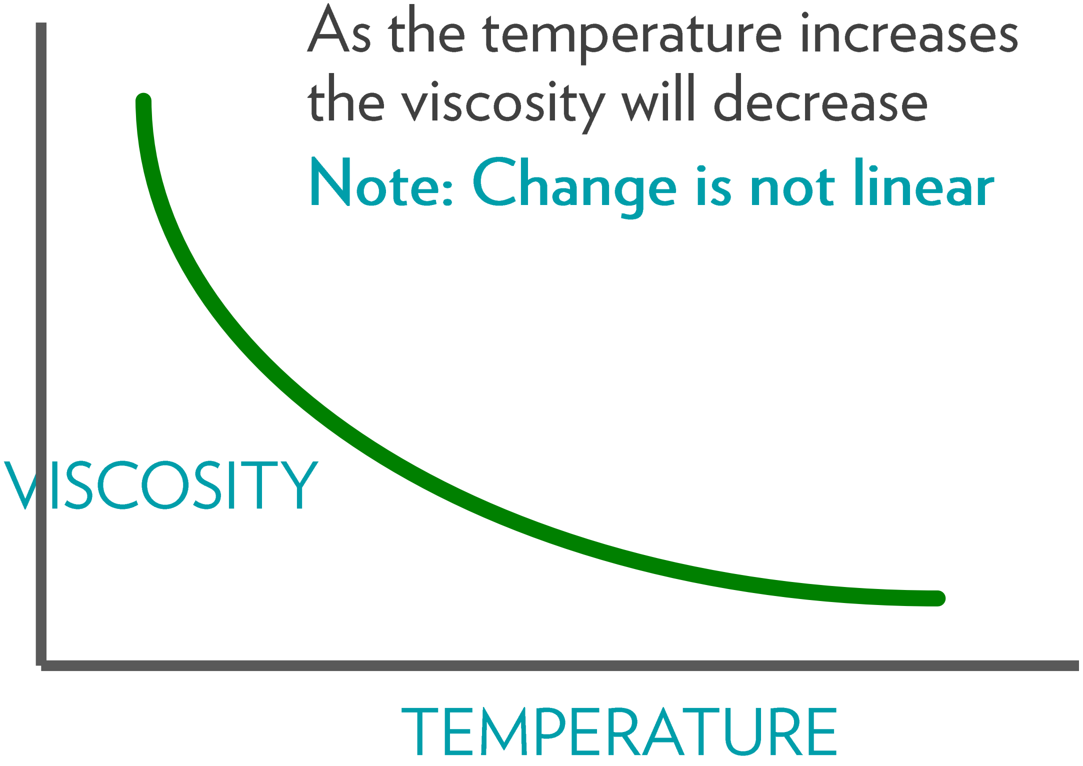
Ref: https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20100021927.pdf

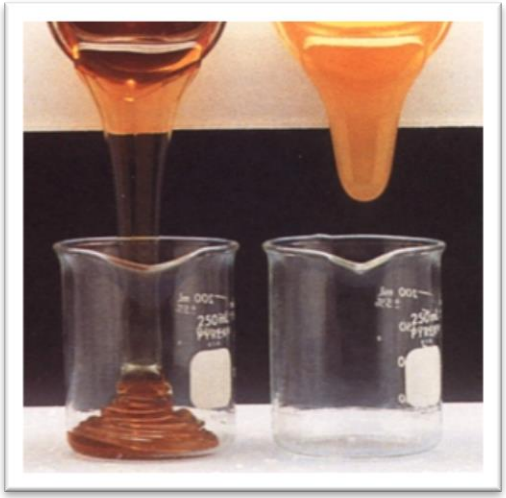
Extreme Temperatures

Temperature vs Viscosity

As the temperature increases the viscosity will decrease

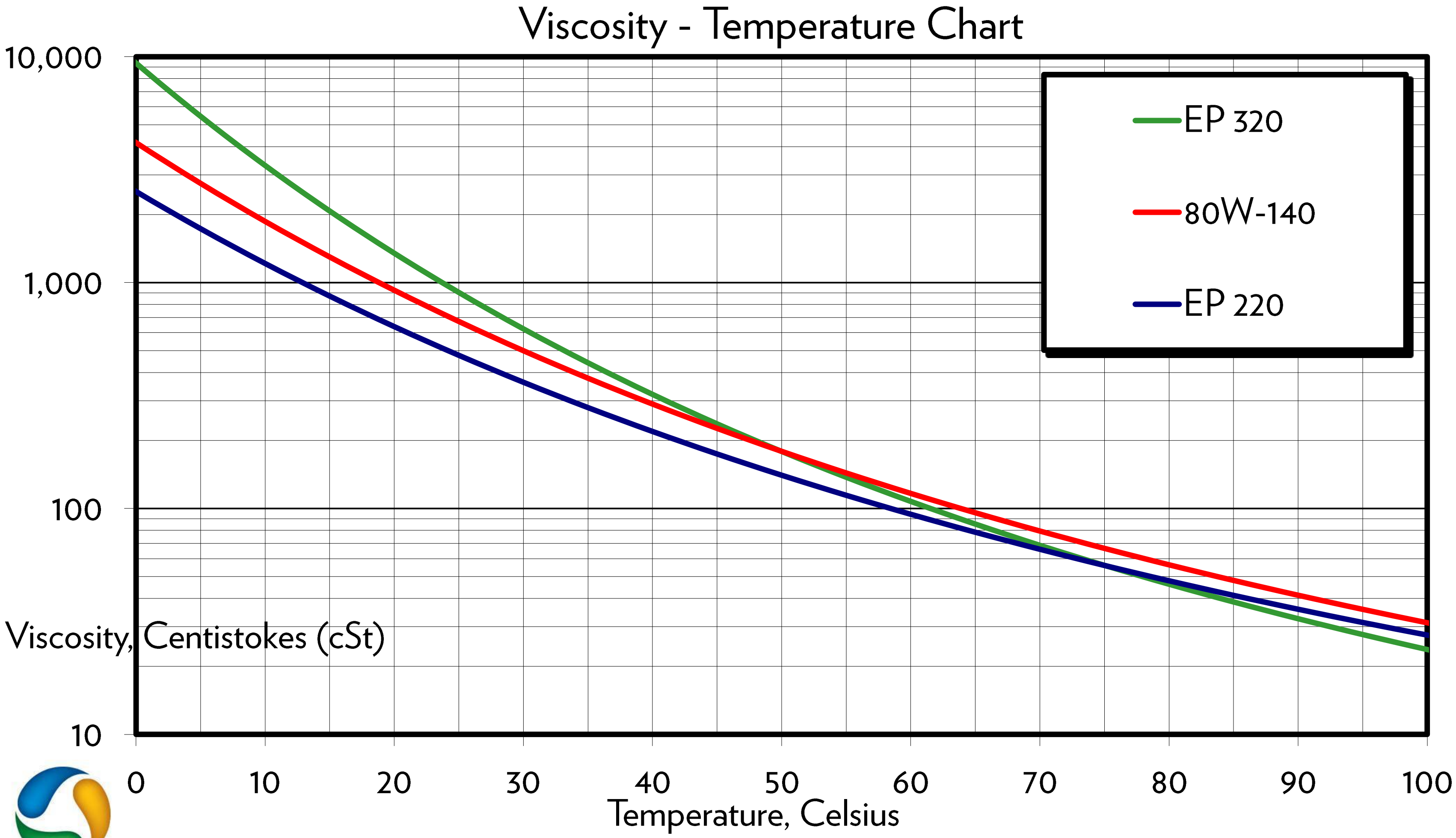
Note: Change is not linear



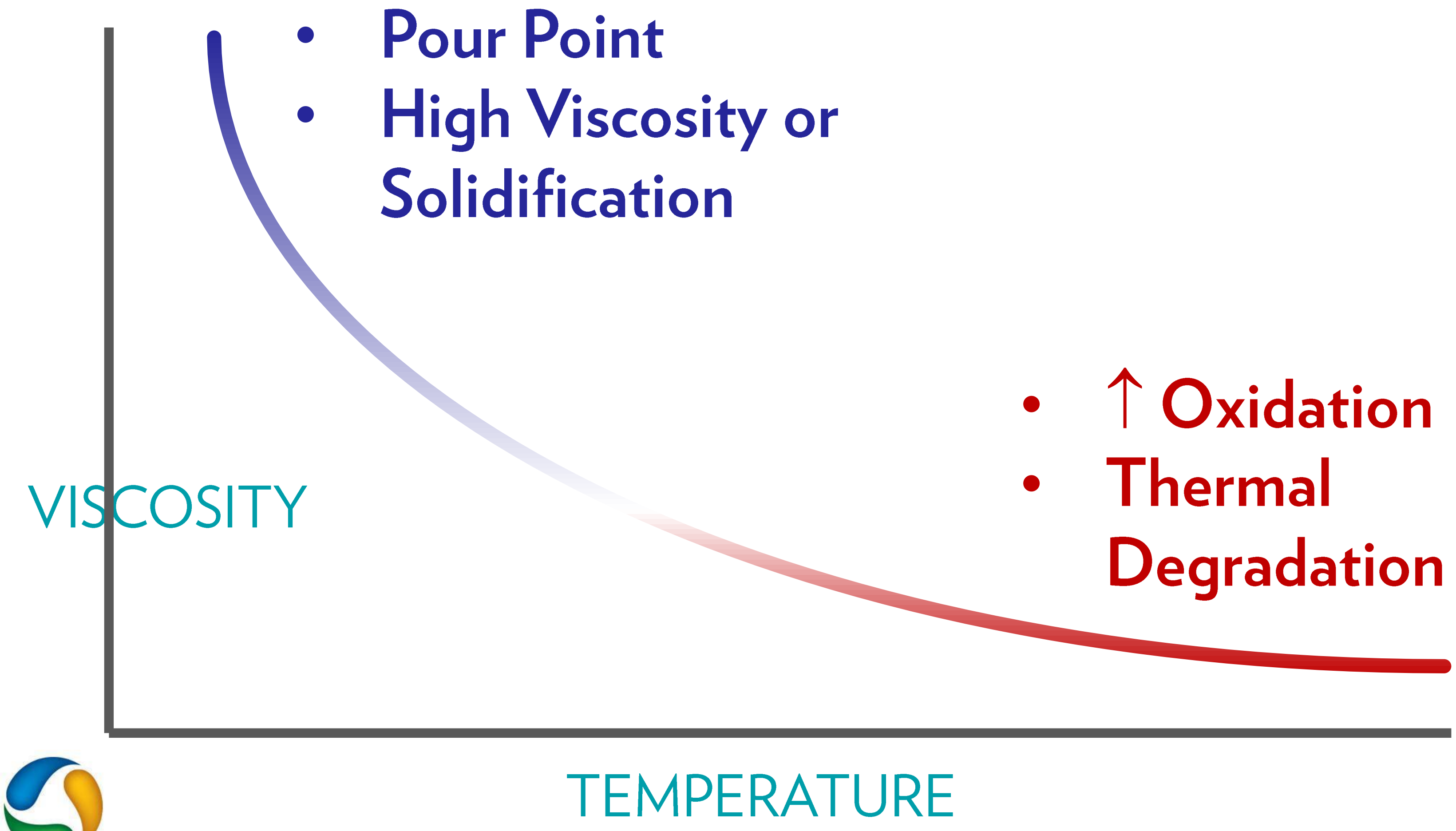


Courtesy Imperial Oil

Normal Operating Temperatures



How do we deal with the extremes?



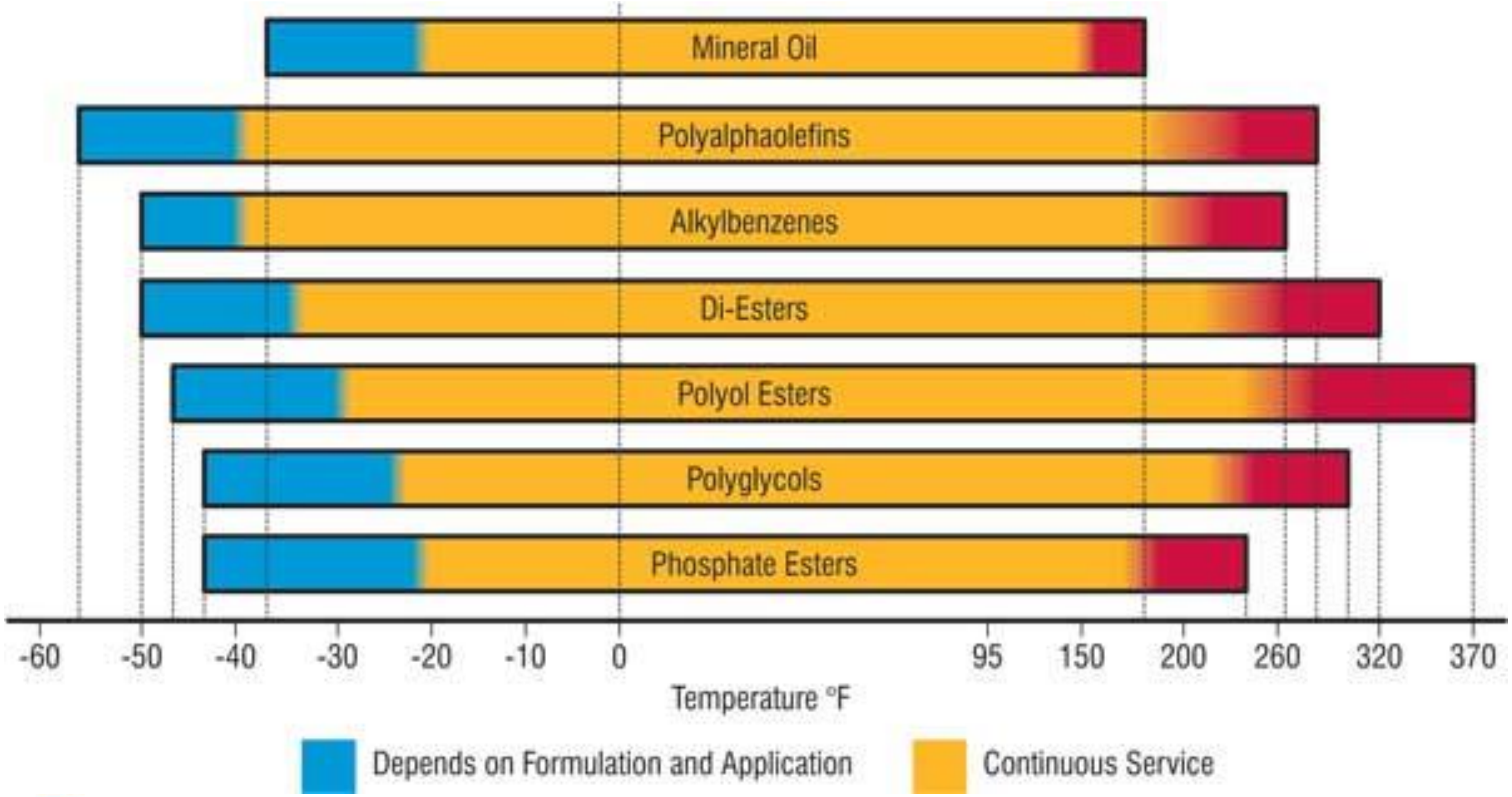
- Pour Point
- High Viscosity or Solidification

- ↑ Oxidation
- Thermal Degradation

Additives → VII et al.

- Detergents
- Dispersants
- Antioxidants
- Antiwear
- Etc.

Change the Chemistry



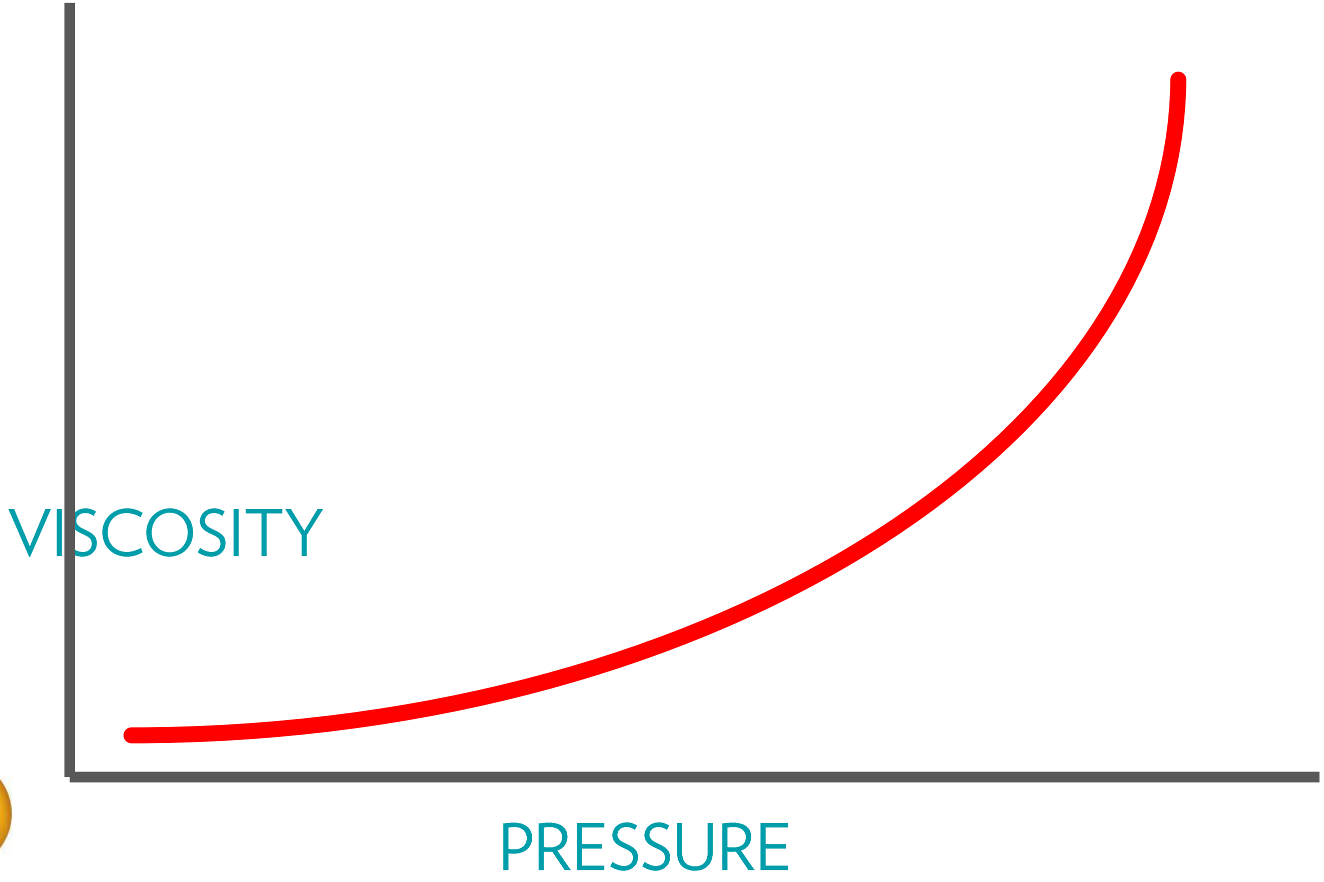
Ref: http://garage.grumpysperformance.com/index.php?threads/which-oil-what-viscosity.1334/

Remove Impurities

Extreme Pressures

Viscosity

Viscosity increases with pressure

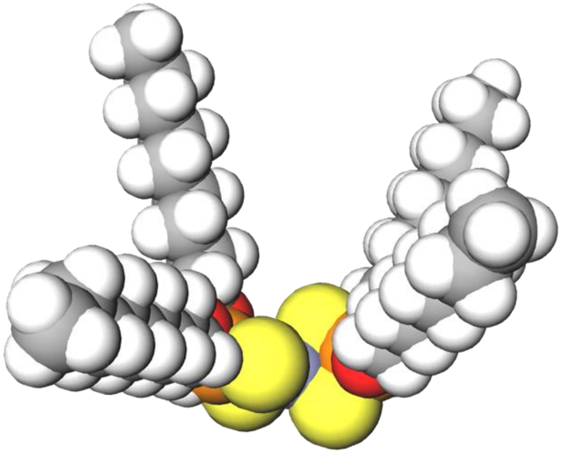


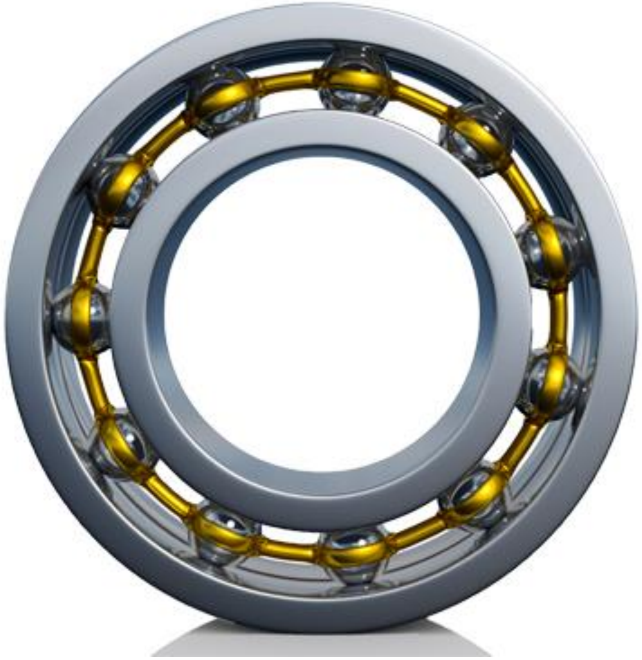
Dealing with the Pressure

Detergents

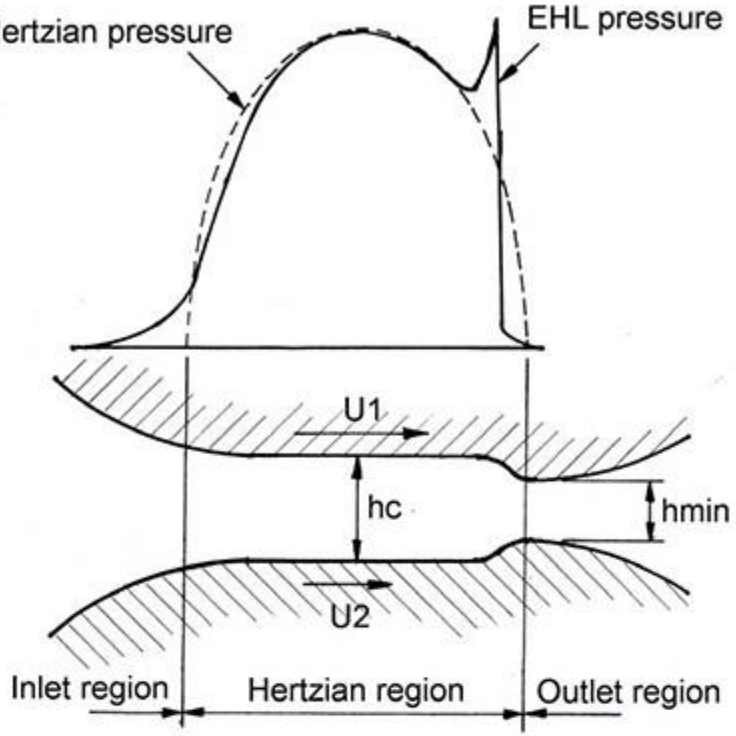
Antiwear Additives

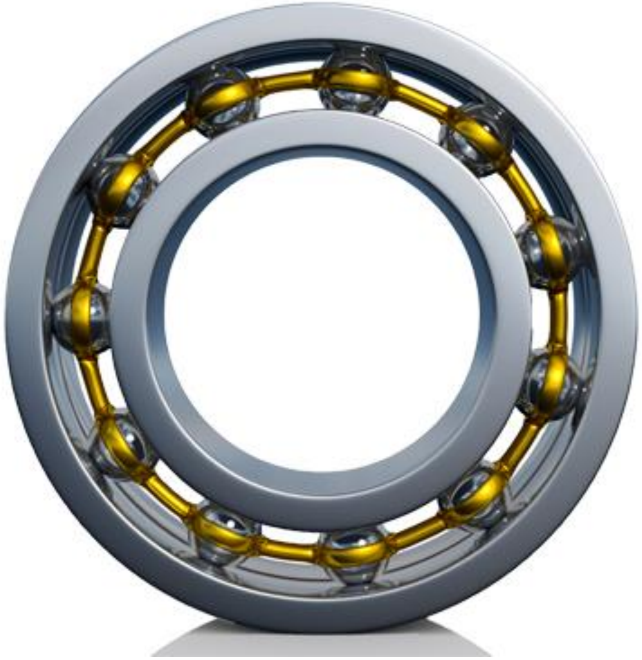
Extreme Pressure Additives





Dealing with the Pressure



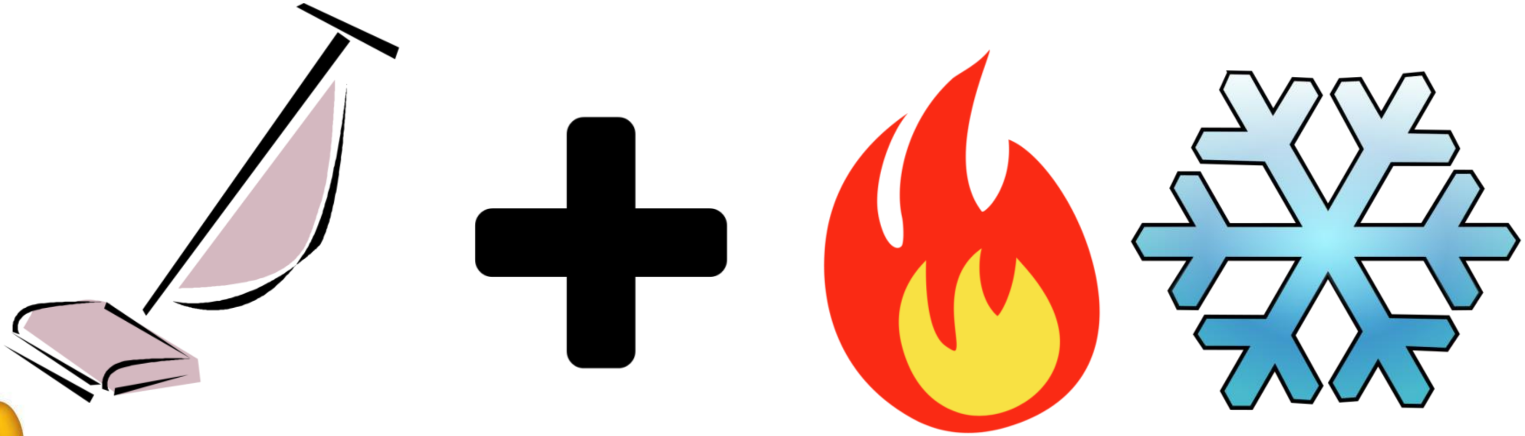


Ref: https://www.geartechnology.com/issues/0715/images/lubrication1.jpg

Extremes

What about extremely low pressure?

AND temperature extremes?



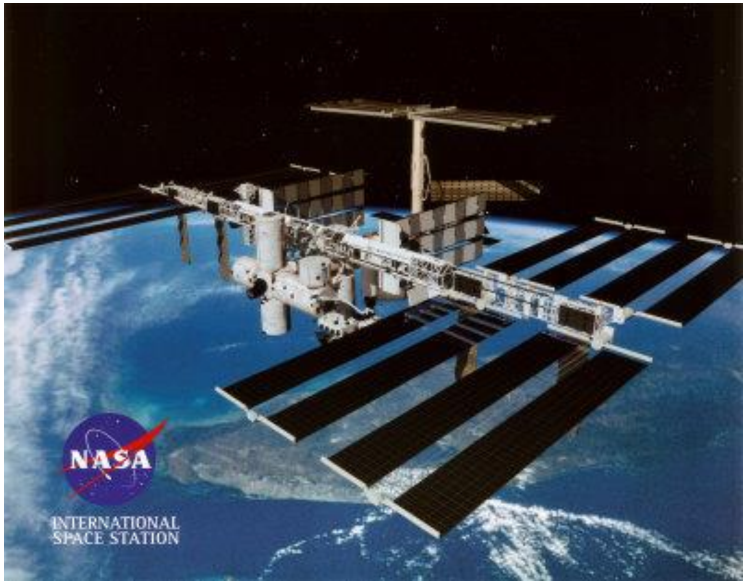
Space Applications

Challenges:

- low ambient temperatures
- wide temperature swings
- solar flux
- cosmic radiation

On the Moon or Mars:

- fine particulate (dust)



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Space Applications

ISS Challenges:

- heat doesn’t conduct
- hot air doesn’t rise
- radiators are too cold for liquid water

No molecules for conduction or convection, only radiation!

Ref: https://science.nasa.gov/science-news/science-at-nasa/2001/ast21mar_1

Space Applications

Other technical challenges:

- loss of lubricant by outgassing
- change in creep properties of the lubricant
- change in lubricant viscosity as a result

- change in tendency for lubricant to flow back between contacting surfaces
- differential temperatures cause oil/grease lubricant to creep toward colder surface (eg. Bearing races)
- lack of gravity changes surface energy of a system

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Ref: Lubrication of Spacecraft Mechanisms, John Hopkins APL Technical Digest, Volume 14, No. 1

Lubricants and Pressure

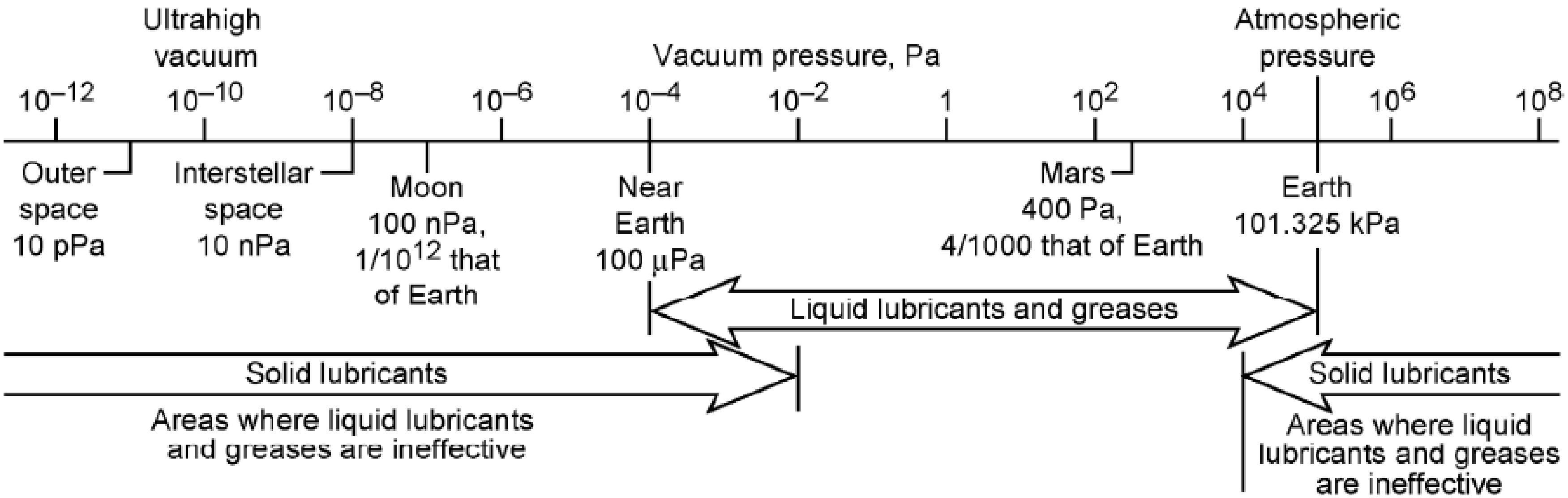


Figure 1.—Ranges of application of various lubricants in vacuum environments. (Figure has both solid and liquid lubricants.)

Ref: Solid Lubricants and Coatings for Extreme Environments: State-of-the-Art Survey, NASA/TM – 2007-214668

Lubricants and Temperature

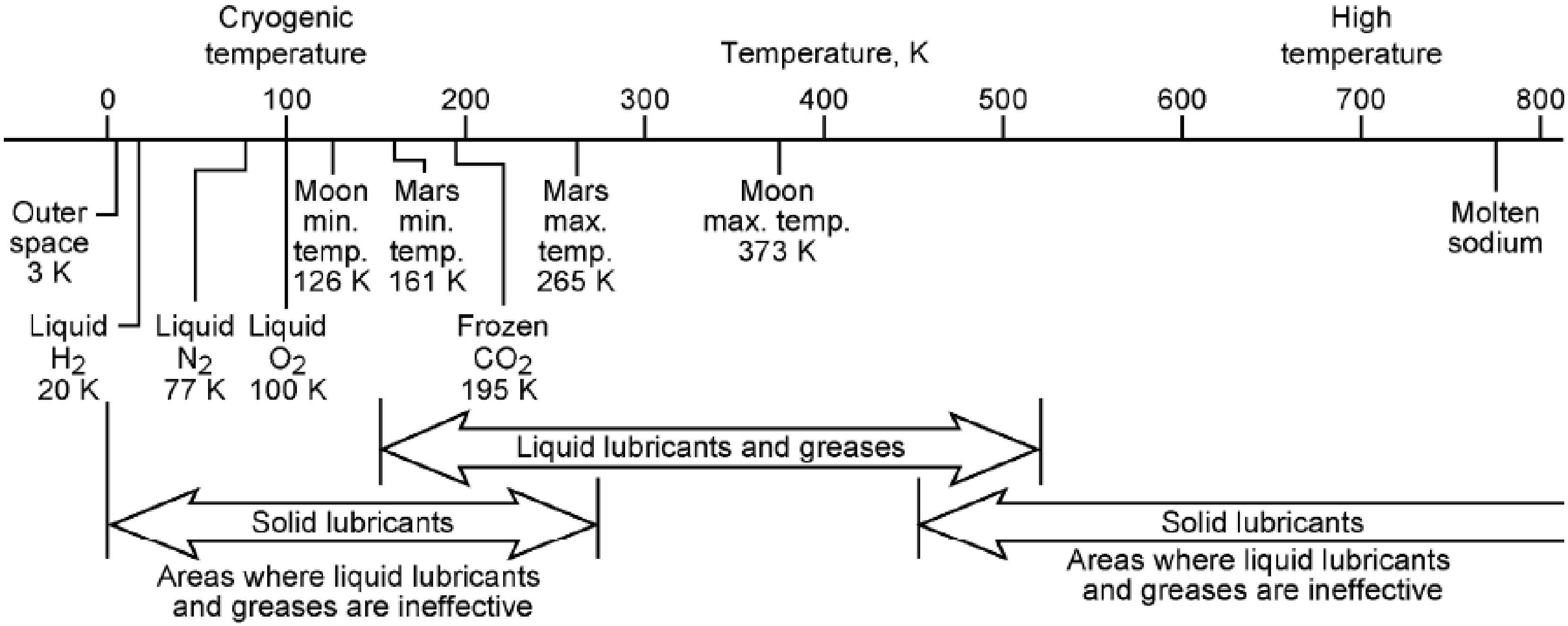


Figure 2.—Ranges of application of various lubricants in cryogenic and high-temperature environments. (Figure has both solid and liquid lubricants.)

Ref: Solid Lubricants and Coatings for Extreme Environments: State-of-the-Art Survey, NASA/TM – 2007-214668

Lubricants and Radiation

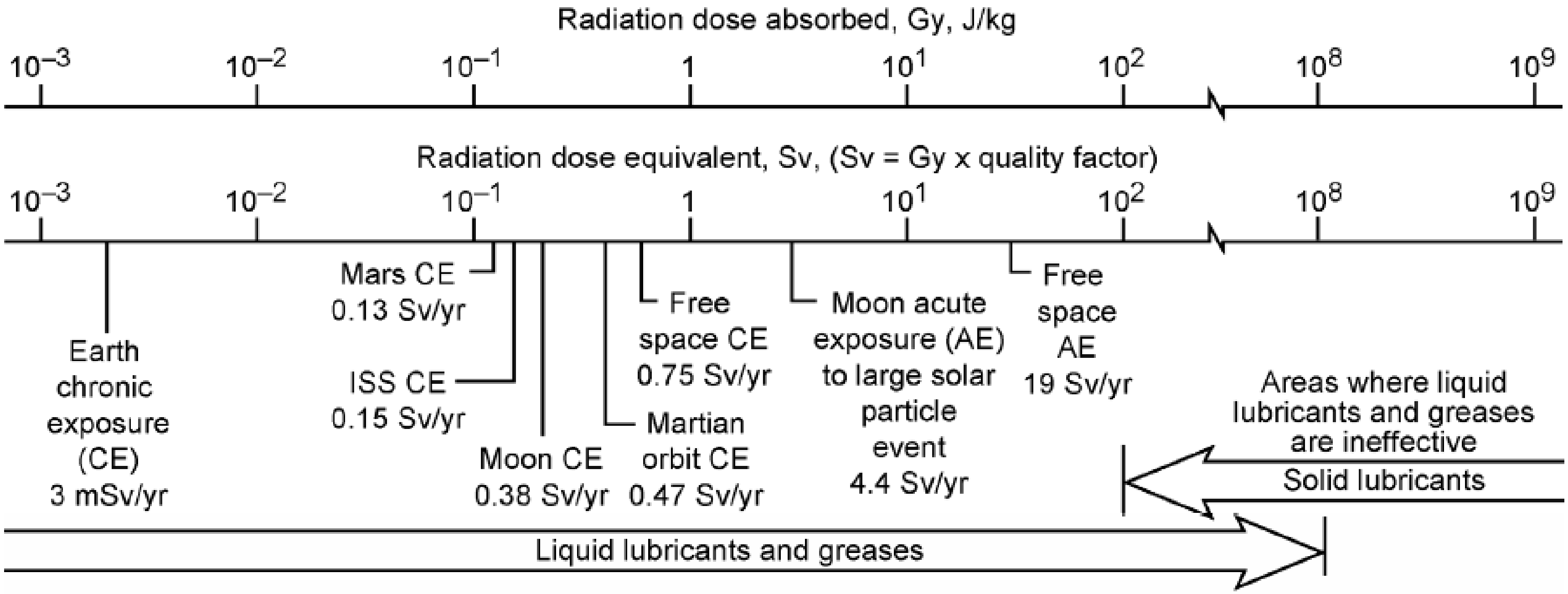
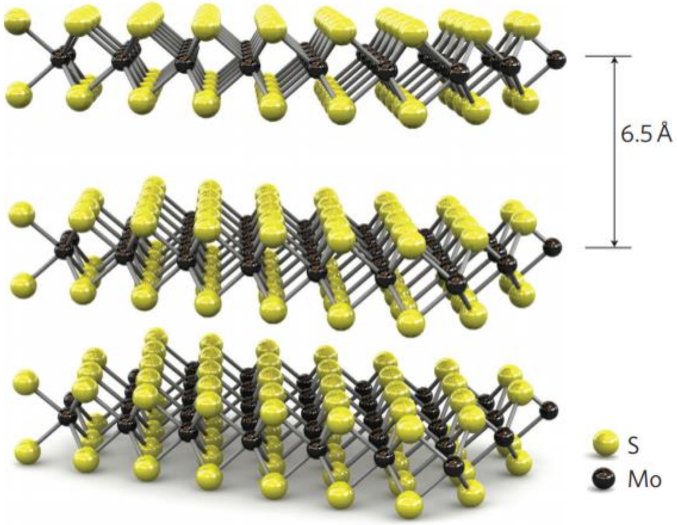


Figure 3.—Ranges of application of various lubricants in radiation environments. (Figure has both solid and liquid lubricants.)

Ref: Solid Lubricants and Coatings for Extreme Environments: State-of-the-Art Survey, NASA/TM – 2007-214668

So what's the Answer?

Solid Lubricants and Specialized Coatings



Advantages of Solid Lubricants

- highly stable at high temperatures, cryogenic temperatures, vacuum, and high pressure environments.
- at high temperatures, solid lubricants can extend the operating temperatures of systems beyond 573 K while maintaining relatively low coefficients of friction.
- in cryogenic temperatures, solid lubricants can extend the operating temperatures of systems down to 0 K.

Ref: Solid Lubricants and Coatings for Extreme Environments: State-of-the-Art Survey, NASA/TM – 2007-214668

Advantages of Solid Lubricants

- in radiation environments, solid lubricants can extend the operation of systems beyond 106 rads (radiation dose absorbed of 104 J/kg) where liquid lubricants would decompose.
- In high dust areas, hard solid lubricants, such as diamond-like carbon, are useful in areas where liquid lubricants tend to pick up dust. These contaminants readily form a grinding paste, causing abrasion and damaging equipment.

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Ref: Solid Lubricants and Coatings for Extreme Environments: State-of-the-Art Survey, NASA/TM – 2007-214668

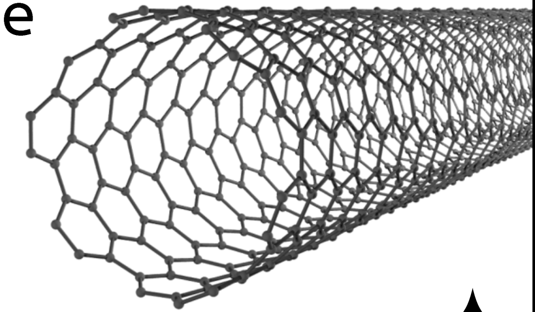
Advantages of Solid Lubricants

- in weight-limited spacecraft and rovers, solid lubrication weighs substantially less than liquid lubrication, reducing spacecraft weight.
- under intermittent loading conditions or in corrosive environments, liquid lubricants become contaminated. When equipment is stored or is idle for prolonged periods, solid lubricants provide permanent, satisfactory lubrication.
- solid lubricants are good for hard to access areas.

Ref: Solid Lubricants and Coatings for Extreme Environments: State-of-the-Art Survey, NASA/TM – 2007-214668

Disadvantages of Solid Lubricants

- have higher coefficients of friction and wear than oil/grease lubricants.
- have poor heat dissipation with low thermal conductivity.
- have poor self-healing properties. Broken or damaged solid films shorten the useful life of the lubricant.
- have undesirable colour. ie. graphite and carbon nanotubules.



Ref: Solid Lubricants and Coatings for Extreme Environments: State-of-the-Art Survey, NASA/TM – 2007-214668

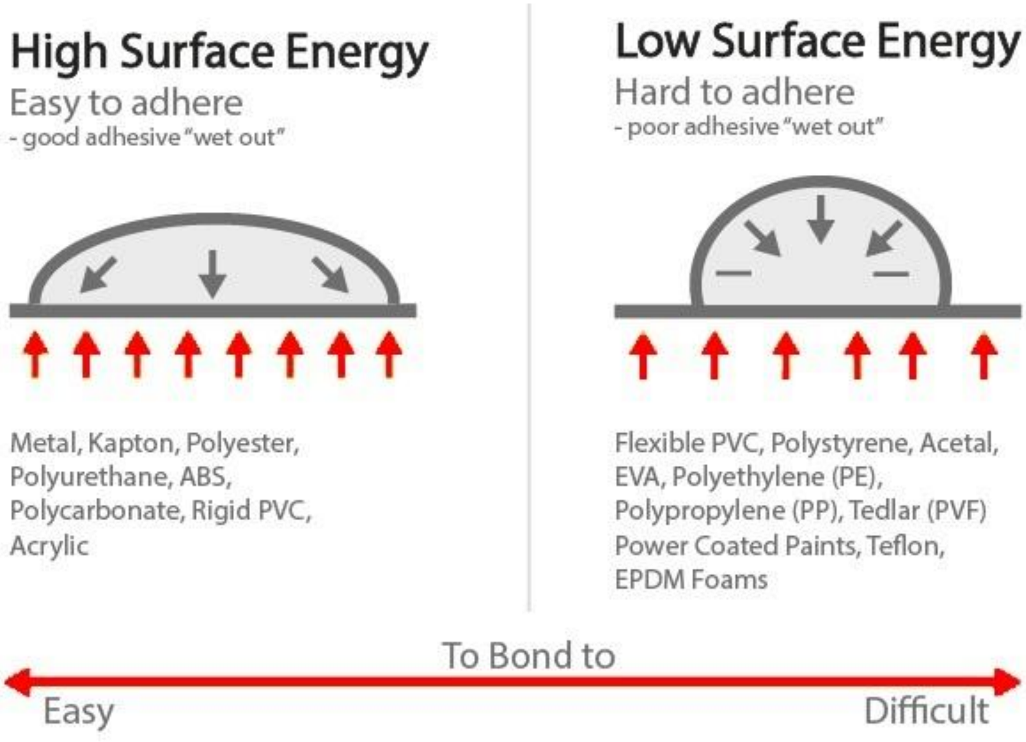
Considerations for Solid Lubricants

- How are they attached to the substrate?
- Strengths and surface energies?
- How do they degrade?
- Can they self-heal?
- What is their useful life?
- Can they easily be reapplied?
- What are their performance characteristics?

Ref: Solid Lubricants and Coatings for Extreme Environments: State-of-the-Art Survey, NASA/TM – 2007-214668

Aside: What is Surface Energy?

Surface energy is the work per unit area done by the force that creates the new **surface**. The molecules on the **surface** of a liquid are packed due to unbalanced inter-molecular forces than the molecules at the center. This means there is a high **energy** density at the **surface** of a liquid.



High Surface Energy

Easy to adhere

- good adhesive "wet out"

Metal, Kapton, Polyester, Polyurethane, ABS, Polycarbonate, Rigid PVC, Acrylic

Low Surface Energy

Hard to adhere

- poor adhesive "wet out"

Flexible PVC, Polystyrene, Acetal, EVA, Polyethylene (PE), Polypropylene (PP), Tedlar (PVF) Power Coated Paints, Teflon, EPDM Foams

To Bond to

Easy

Difficult

Ref: https://www.quora.com/What-is-the-difference-between-surface-tension-and-surface-energy

Performance Characteristics for Solid Lubricants

- Extreme abrasion and wear resistance
- Ultrahard surface
- High impact strength
- Low surface energy
- High release properties
- Low friction coefficient
- Permanent dryness to resist galling
- Protection from:
  - Erosion
  - Radiation
  - Chemical attack
- Nontoxicity
- Conformance to complex geometry
- Excellent corrosion resistance
- Wide temperature range

Ref: Solid Lubricants and Coatings for Extreme Environments: State-of-the-Art Survey, NASA/TM – 2007-214668

For High Heat Dissipation:

The following may be deposited on an interlayer:

- carbon nanotubules
- nanocrystalline diamond coating
- metal-doped diamond coatings
- metal-doped diamond like carbon coatings
- soft metal films (gold, silver, copper, lead, etc.)

Potential applications: furnaces, metalworking equipment, compressors, nuclear reactors, molten metal plating equipment, oven door locks.

Ref: Solid Lubricants and Coatings for Extreme Environments: State-of-the-Art Survey, NASA/TM – 2007-214668

For Translucency or Transparency:

The following may be deposited on an interlayer:

- nanocrystalline diamond coating
- microcrystalline diamond coating
- fluorinated and unflorinated diamond like carbon coatings

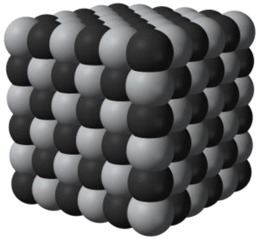
Potential applications: high temperature camera lenses, dental appliances, reflective mirror surfaces, solar panels, die lubricants, metal working equipment

Ref: Solid Lubricants and Coatings for Extreme Environments: State-of-the-Art Survey, NASA/TM – 2007-214668

To Avoid Contaminating Product or the Environment:

The following may be deposited on an interlayer:

- TiO_2 grown on 55Ni-45Ti and Titanium based alloys
- TiO_2 coatings
- TiC coatings



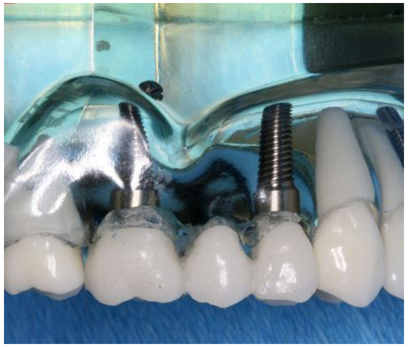
Potential applications: microscopes and cameras, spectroscopes, medical and dental equipment, artificial implants, food-processing machines, optical equipment, metalworking equipment, hard disks and tape recorders, textile equipment, paper-processing machines, business machines.

Ref: Solid Lubricants and Coatings for Extreme Environments: State-of-the-Art Survey, NASA/TM – 2007-214668

For High Particulate Environments:

The following may be deposited on an interlayer:

- ceramic coatings – BN, B_4C, VC, AlN, CN_x, TiO_2, SiC, Si_3N_4 and SiO_2.
- Multi-layered composite coatings – WC/C, MoS_2/C, WS_2/C, and TiC/C.
- nanocrystalline diamond coatings
- microcrystalline diamond coatings
- diamond like carbon coatings

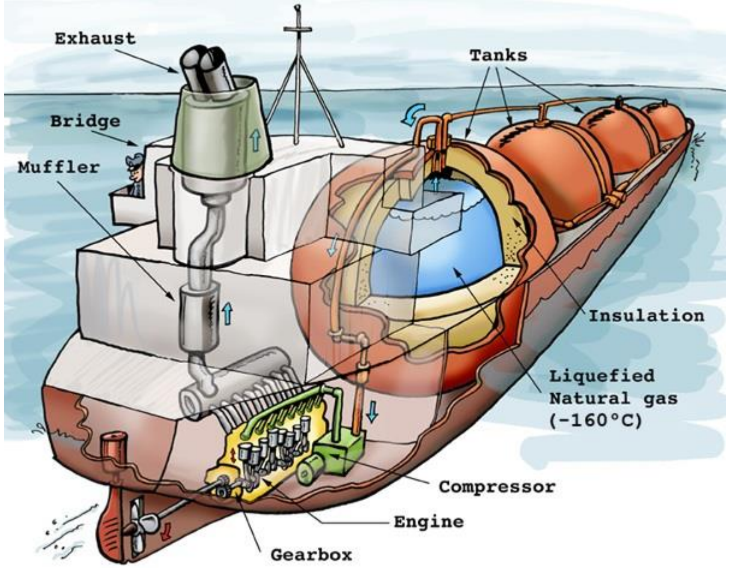


Potential applications: agriculture and mining equipment, off-road vehicles, construction equipment, textile equipment, dental implants.

Ref: Solid Lubricants and Coatings for Extreme Environments: State-of-the-Art Survey, NASA/TM – 2007-214668

Picture Ref: By Coronation Dental Specialty Group[1] - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=29443056

For Cryogenic Applications



- Turbopumps
- Liquid nitrogen pumps
- Butane pumps
- Freon pumps
- Liquid natural gas pumps
- Liquid propane pumps
- Refrigeration plants and equipment

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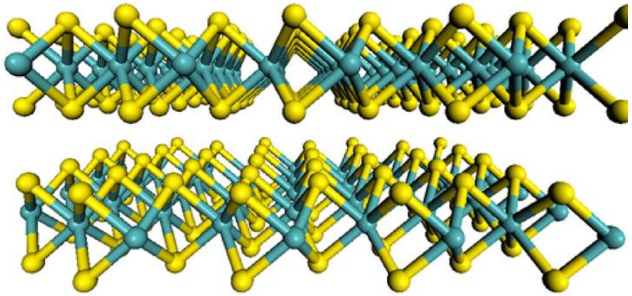
Picture Ref: By Welleman at Dutch Wikipedia, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=1850695

MoS_2:

- Low coefficient of friction in vacuum and atmosphere
- Does not rely on absorbed vapours or moisture
- Thermally stable in non-oxidizing environments to 1373 K
- Thermally stable in oxygen atmosphere to 673 K
- High load carrying capability, superior to graphite and PTFE
- Hexagonal crystalline structure with easy shear
- Effective in a vacuum where graphite is not



Ref: Solid Lubricants and Coatings for Extreme Environments: State-of-the-Art Survey, NASA/TM – 2007-214668

Picture Ref: http://news.mit.edu/2012/graphene-molybdenum-disulfide-flat-materials-0823

Don’t count out the old standard…

CASTROL INDUSTRIAL LUBRICATES NASA’S WHEELS OF SUCCESS

Tuesday, January 22, 2013: When NASA’s Curiosity rover (“Curiosity”) began its exciting mission on Mars in early August, an innovative Castrol Industrial lubricant called Castrol Braycote 601 EF helped ensure the smooth operation of Curiosity, from its wheels to its cameras.

“If it’s a moveable part, it most likely has Castrol Braycote 601 EF on it,” said Keith Campbell, business development manager for Castrol Industrial Lubricants, whose team has led the development of this technology, working closely with NASA. “In fact, the success of the Curiosity mission in part depends on the success of this grease, which has been formulated for the space programme to perform in temperatures ranging from minus 80 degrees to 204 degrees Celsius.”

It is not only the lubricity that this product provides which is important but, with the low outgassing characteristic of Castrol Braycote 601 EF, this product should ensure the many sensitive instruments and components on the rover can function as required, allowing Curiosity to investigate Mars; its atmosphere and its land.
“Castrol Braycote 601 EF resists what’s known as ‘outgassing’ or the evaporative loss of the grease itself, meaning that instruments work at their optimum levels, even at extremely high temperatures,” Campbell said.

The lubricant is frequently used in space applications including the Space Shuttle, satellites, and the International Space Station. It is an excellent wide temperature grease for space and vacuum manufacturing applications, and should also be considered in any application where there are hostile chemicals or extreme environmental conditions that would preclude the use of an ordinary lubricant.

Typical applications include ball and roller bearings, gears, and as an assembly lubricant for O-rings and elastomers. “We are also working closely with NASA to develop other technical lubricants that meet the ever increasing challenges of space exploration,” Campbell concluded.

Other Extreme Environments

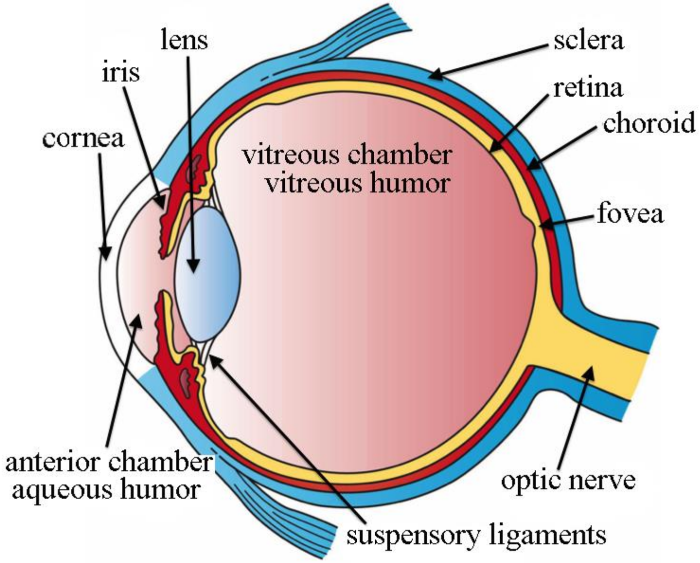
Studies have shown that the human body produces a graphitic carbon layer between components of metal-on-metal hip implants.

Scientists expected a layer made of proteins and other biological material. This may lead to solid coatings being used in implants going forward.

Ref: https://www.nih.gov/news-events/nih-research-matters/body-produces-industrial-lubricant-metal-hip-implants

Vitreous Substitutes

Human vitreous fluid is a hydrogel made of 99% water with Type II collagen fibrils and hyaluronic acid.



- Early 20th Century → replaced with air, sulphur hexafluoride, or n-perfluoropropane
- 1962 → polydimethylsilicone, in 1000 or 5000 Cst viscosities, toxicity concerns
- Perfluoronated hydrocarbons being replaced with saline.

Ref: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2629432/

Ref: By Artwork by Holly Fischer - http://open.umich.edu/education/med/resources/second-look-series/materials - Eye Slide 3, CC BY 3.0, https://commons.wikimedia.org/w/index.php?curid=24367145

A few other examples

- Diamond like carbon used on the surface of titanium spinal total disc replacements.
- PMMA – Poly(methyl methacrylate) used as bone cement and repair, intraocular lens, or dialysis membranes
- PP – polypropylene used in suture material
- UHMWPE – ultrahigh molecular weight polyethylene – stable and low friction polymer for joint prostheses
- PEEK – Polyether ether ketone - orthopedics

Ref: www.sciencedirecct.com/science/article/pii/S2405451815000434

Thank you for the opportunity to present.

Comments, concerns, or questions?