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Simple molecules <1 nm
DNA proteins nm
Nanoparticle nm

10^{-10} 10^{-9} 10^{-8} 10^{-7} 10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2}

red blood cell ~5 μm (SEM)
diatom 30 μm

bacteria 1 μm
Nanoparticle linkages to proteins

- Much more complex than with DNA
- More amino acids to interact with
- Where does nanoparticle link?
- Structure key to function

Site specific labeling of protein with NP that preserves protein structure
NP-cytochrome c interfaces

Site specifically link 1.4nm Au NPs to *Saccharomyces cerevisiae* cytochrome c:

```
TEFKAGSAKKGATLFKTRCLQCHTVEKGGPHKVGNLHGIIFGRHSGQAEGYSYTDA
IKKKNVLWDENNMSEYLTNPKKYIPGTKMAFGGLKEKDRNDLITYLKKACE
```

- Charged ligands result in greatest denaturation

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Amino acids in vicinity

- Many charged amino acids closest to linking site
- Systematic study:
  - Vary NP position
  - Vary NP ligand
  - Vary NP size
  - Vary NP material

- Electrostatic interactions with amino acids in local vicinity

Orthogonal heating of NPs

\[ P = f (\text{material properties, } R, H, \omega) \]

3-Variable Tuning = Multiple Control

★ independent heating possible

A. Wijaya et al., 2006