TABLE 4-1

Anomalous Physical Properties of Water and Their Effects on Seawater and the Ocean*

PROPERTY	COMPARISON WITH OTHER SUBSTANCES	IMPORTANCE IN OCEAN
Heat capacity	Highest of all solids and liquids except liquid ammonia	Prevents extreme ranges in ocean temperature Heat transfer by currents is large
Latent heat of fusion	Highest except ammonia	Acts as thermostat at freezing point owing to uptake or release of latent heat
Latent heat of evaporation	Highest of all substances	Important in heat and water transfers to atmosphere
Thermal expansion	Temperature of maximum density decreases with increasing salinity. For pure water, it is at 4°C.	Freshwater and dilute seawaters reach maximum density at temperatures above freezing point (non-linear $\rho = f(\text{temp})$)
Surface tension	Highest of all liquids	Controls drop formation and behavior; also surface phenomena, such as capillary waves
Dissolving power	Dissolves more substances and in greater quantities than any other liquid	
Transparency	Relatively great	Absorption of radiant energy is large in infrared and ultraviolet. In visible portion of energy spectrum there is relatively little selective absorption—hence is "colorless"

* Modified after Sverdrup et al., 1942.

http://rainbow.ldgo.columbia.edu/ees/climate/slides/prop_h2o.gif

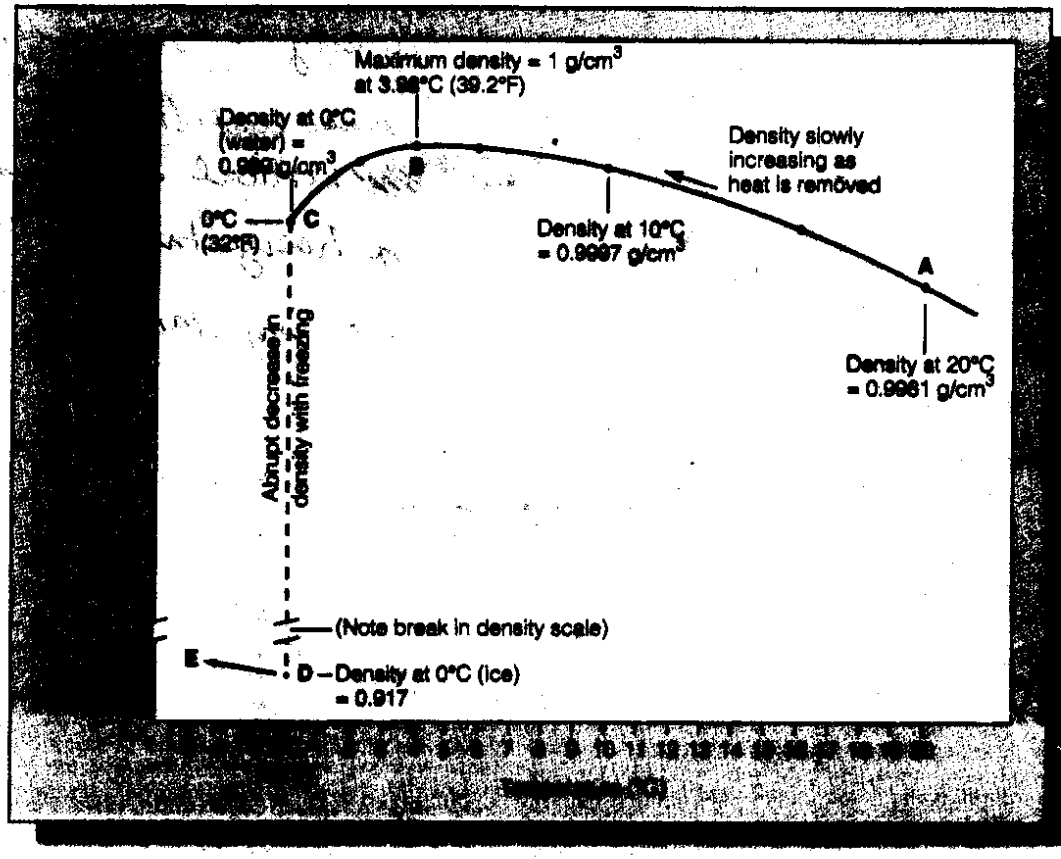


Figure 7.1 The relationship of density to temperature for pure water. Note that points C and D both represent 0°C (32°F) but different densities and thus different states of water. Because the density of ice is less than the density of liquid water, ice floats.

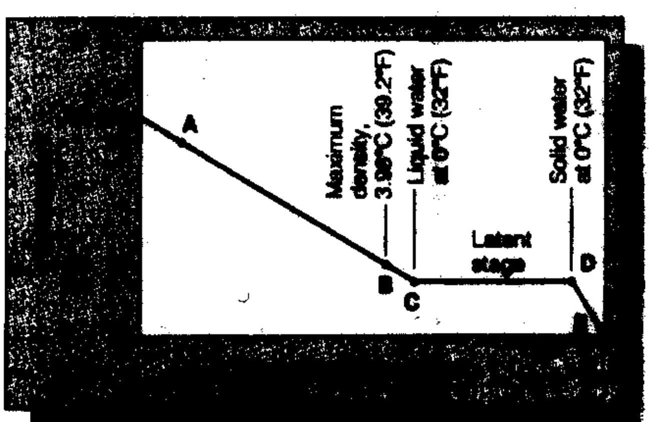


Figure 7.3 A graph of temperature versus heat removal as water freezes (or ice melts). The horizontal line between points C and D represents the latent heat of fusion, when heat is being removed but temperature is not changing. (Note that points A–E on this graph are the same as those in Figure 7.1.)

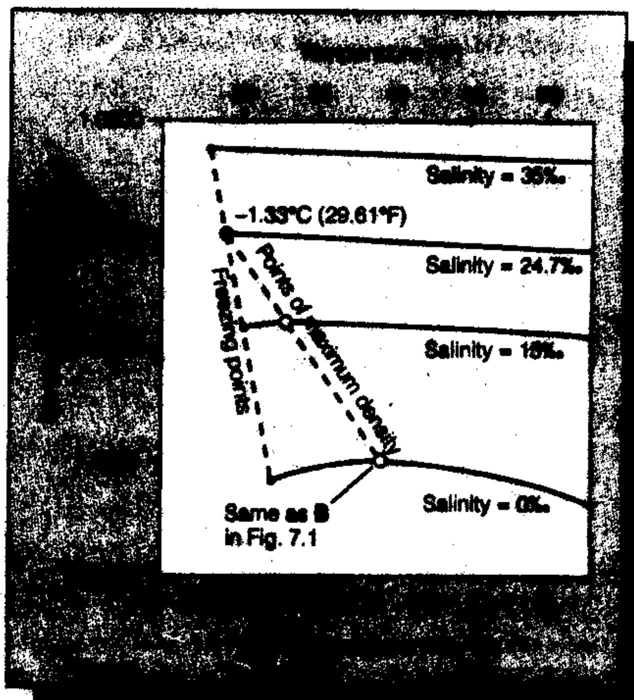


Figure 7.4 The dependence of freezing temperature and temperature of maximum density on salinity. As we saw in Figure 7.1, pure water is densest at 3.98°C (39.2°F) (point B) and its freezing point is 0°C (32°F). Seawater with 10‰ salinity is densest at 0.73°C (33.31°F), and its freezing point is −0.80°C (30.56°F). The temperature of maximum density and freezing point coincide at −1.33°C (29.61°F) in seawater with a salinity of 24.7‰. At salinities greater than 24.7‰, the density of water always decreases as temperature increases.

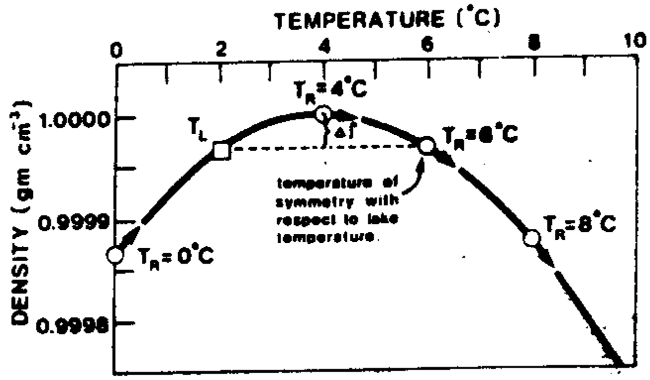


FIG. 2. Relationship between water temperature and density. The symbols T_R and T_L refer to river and lake temperatures, respectively, and denote conditions shown in Fig. 3.

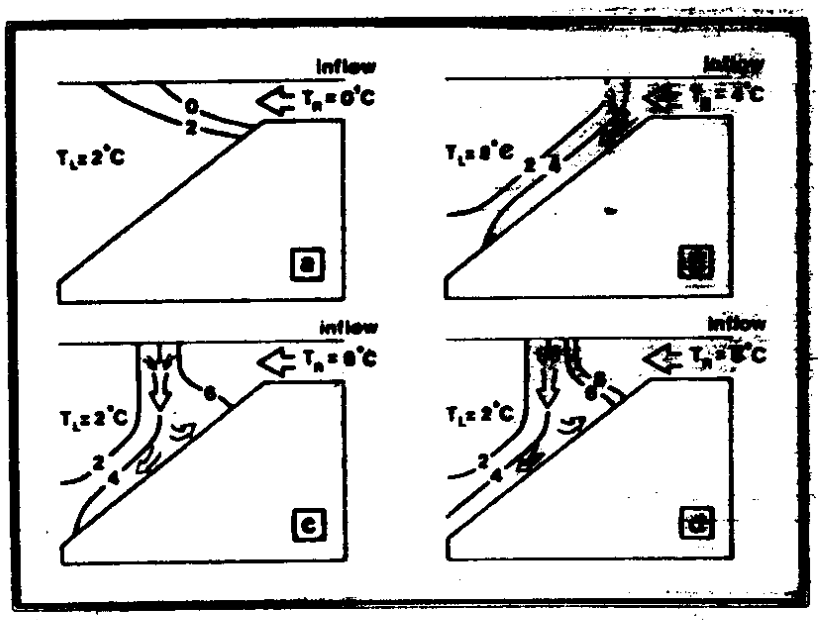
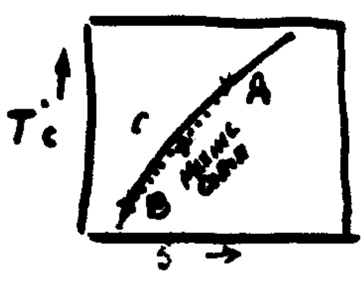


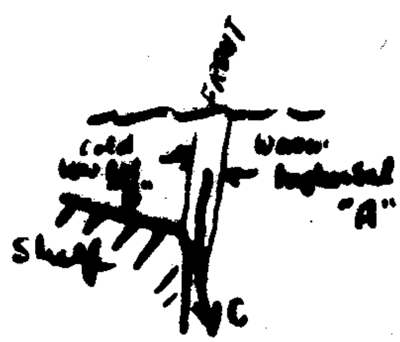
FIG. 3. Schematic illustration of river-induced convective circulation during spring overturn assuming a nearly constant lake temperature of 2°C and a river inflow that warms rapidly from 0 to 8°C

Cabbaling.

can also occur in salt water



$\rho_c > \rho_A, \rho_B$



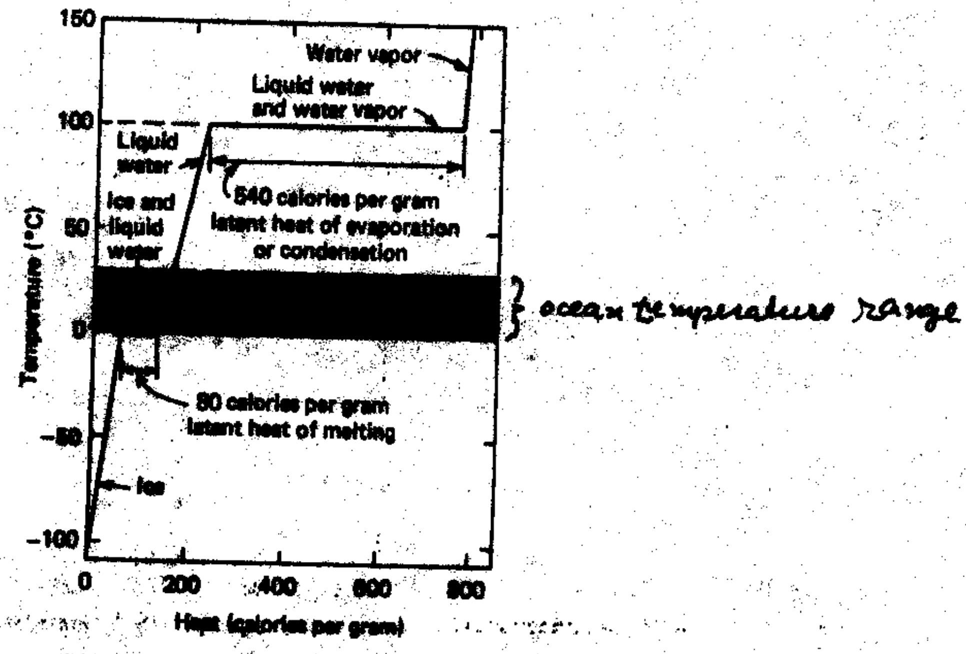
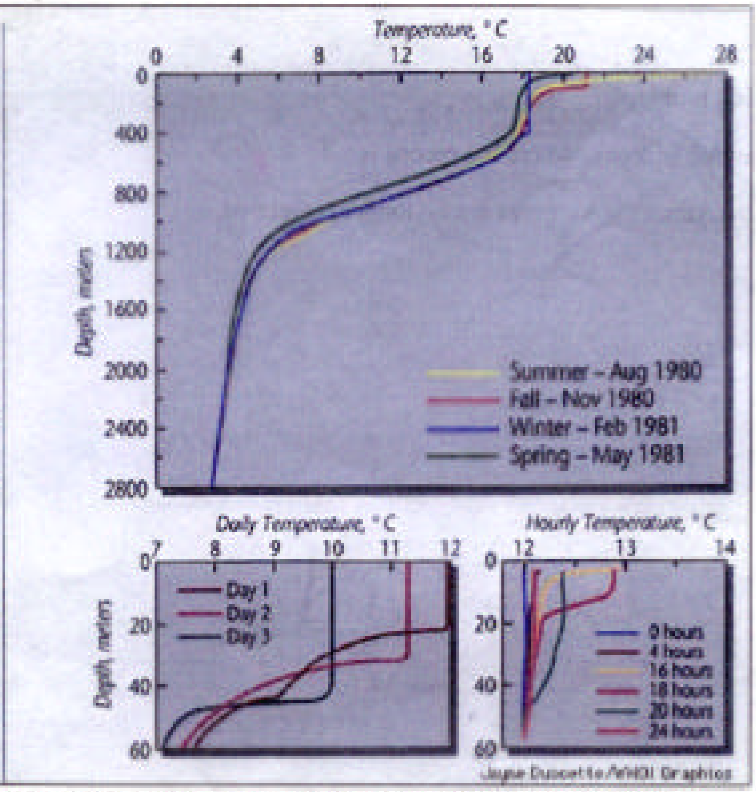


FIGURE 4-6
Temperature changes when heat is added or removed from ice, liquid water, or water vapor. Note that temperatures do not change when mixtures of ice and liquid water or liquid water and water vapor occur together. (Redrawn from M. G. Gross. 1985. *Oceanography*. Columbus Ohio, Charles E. Merrill Publishing Company.)

TEMPERATURE (°C)	LATENT HEAT OF EVAPORATION (calories per gram)
0	595
20	585
100	539

Temperature profiles taken hourly (lower right), daily (lower left), and seasonally (top) reveal the movement of the mixed layer under different conditions. The hourly profile was taken from research platform FLIP during a series of many warm days, ultimately creating a "summer" seasonal profile similar to the yellow tracing above. The daily profile was also taken from FLIP, but during a stormy period, when the cooling and deepening of the mixed layer produces a "winter" seasonal profile much like the blue line above.



Source: Weller, Robert A. and David M. Farmer. **Dynamics of the Ocean Mixed Layer.** *Oceanus,* Summer 1992, Vol. 35, No. 2, p.47.

$\overline{\Delta T}$ = mean seasonal difference in temperature (°C) from the sea surface to depth, **h** (cm)

C = heat capacity of seawater (0.94 cgs)

ρ = density of seawater (1.023 cgs)

Q = seasonal heat storage in ocean surface (mixed) layer, calories

$$Q = \rho \, C \, \overline{\Delta T} \, h$$

<u>for</u> **h** = 100 m = 10^4 cm

$\overline{\Delta T}$ = 3°C

Q = 28849 calories

a layer of atmosphere of the same thickness, **h**, experiencing the same $\overline{\Delta T}$ would be much less:

C_{air} = 0.25

ρ_{air} = 10^{-3}

Q_{air} = 8 calories

ALG/LP

Sigma notation, σ

- $\sigma \equiv (\rho - 1000)$ in mks units, or $(\rho - 1) \times 1000$ in cgs

  Now,

- $\sigma_t \equiv \sigma_{T,S,0}$ while $\sigma_\theta \equiv \sigma_{\theta,S,0}$

  Lastly, $\sigma_P \equiv \sigma_{T,S,P}$ or $\sigma_P \equiv \sigma_{\theta,S,P}$

  Ranges: σ_t, 20 - 28, and σ_P, 20 - 60.

The 'standard' σ_t at $p = 0$, $S = 35.00$, and $T = 10.00$, is $\sigma_t = 26.95$

Scales for the ocean

Temperature (°C)	Salinity (o/∞)	Pressure (dbar)
-2 to 30 $\mu \sim 4$	30 to 38 $\mu = 34.7$	0 to 10^4, $\mu_{\text{bottom}} \sim 3850$

The SI unit for pressure is the Pascal.
1 Pa $= 1$ kg / ms^2 1 dbar $= 10^4$ Pa.
Why use dbar? 1 dbar $\sim$ 1 meter depth in the ocean.

Hydrostatic Relationship:

$$\frac{\Delta P}{\Delta z} = g \rho$$

CGS
$g = 10^3$ cm/sec^2
$\rho = 1$ gm/cm^3
$\Delta z = 1m = 10^2$ cm
1 bar = 10^6 dynes/cm^2
$\Delta P = 1$ deci-bar (db)

MKS
$g = 10$ m/sec^2
$\rho = 10^3$ kg/m^3
$\Delta z = 1$ m
1 bar = 10^5 Newton/m^2
$\Delta P = 1$ db

The Equation of State

- $\frac{d\alpha}{\alpha} = \beta dT - \mathrm{b}dS - \mathrm{K}dP$
- $\beta \equiv \frac{1}{\alpha}\frac{\partial \alpha}{\partial T}\Big|_{\mathrm{S,P}}$: The Coefficient of Thermal Expansion
- $\mathrm{b} \equiv -\frac{1}{\alpha}\frac{\partial \alpha}{\partial S}\Big|_{\mathrm{T,P}}$: The Coefficient of Saline Contraction
- $\mathrm{K} \equiv -\frac{1}{\alpha}\frac{\partial \alpha}{\partial P}\Big|_{\mathrm{S,T}}$: The Coefficient of Compressibility

  You may ask, why all the negative signs that cancel each other out – so that β, b, and K are greater than 0.

- **b** $\sim$ constant. This means that salinity has about the same effect on water whether it is at great depth or at the surface, whether it is warm or cold.

- $\beta > 0$ for S > 24.695. $\beta = \beta(T)$ What does this mean? You may have heard that there is a density maximum for water at 4°C. This is true only for fresh water. Sea water, with S > 24.695, is increasingly denser the colder it gets.

  $\frac{\partial \beta}{\partial T} > 0$ means β is smaller for cold water, i.e., warm water experiences a larger change in density for a given dT than does cold water. This has implications for the stability of the water column and the strength of vertical mixing, especially in polar regions, and the phenomenon of cabbeling.

Cabbeling Two parent water masses of equal density mix and produce a water type denser than either original, which sinks. This is especially a case in polar regions, where δS is a determining factor in relative densities, and the water column stability is weak.

- Compressiblity, **K**: $\frac{\partial K}{\partial T} < 0$, or colder water is more compressible than warm water. This produces a rotation of σ_{p} lines in T-S space.

  $\frac{\partial K}{\partial P} < 0$, or water at depth (under pressure) is less compressible than surface water, for the same change in pressure.

  $\frac{\partial K}{\partial S} < 0$, or salty water is less compressible than fresh water – this makes sense if you think of the salt as taking up spaces left between water molecules.

- **Scales:**

  $\beta = \mathrm{O}(1.4 \times 10^{-4}/^{\circ}\,\mathrm{C})$

  $\mathrm{K} = \mathrm{O}(4 - 5 \times 10^{-6}/\mathrm{dbar})$

  $\mathrm{b} = \mathrm{O}(7 \times 10^{-4}/_{\circ/\infty})$

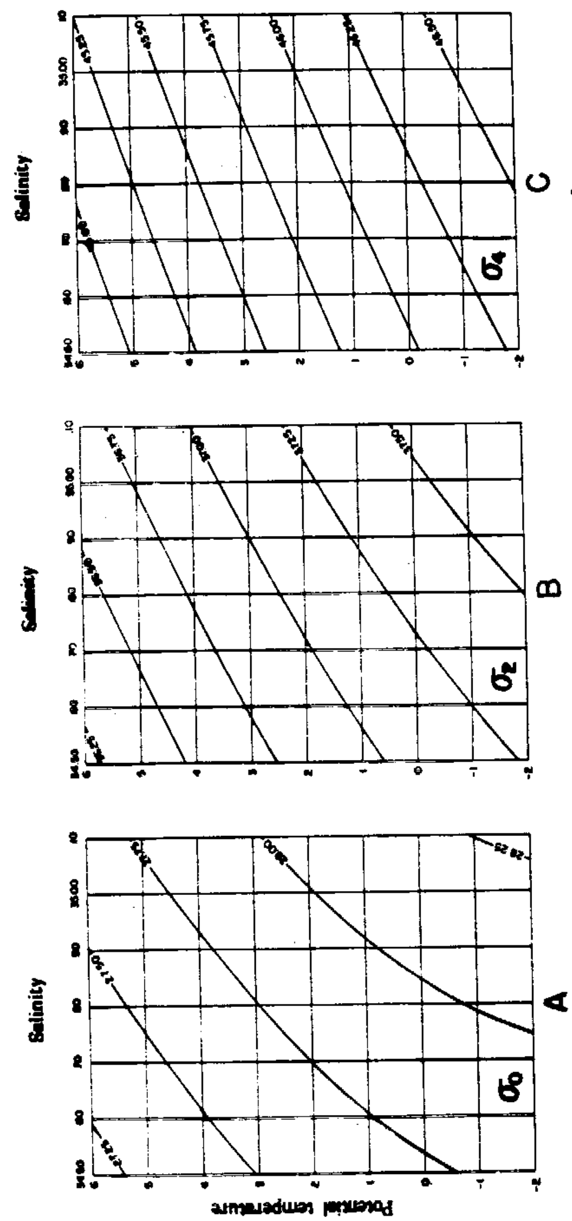


Fig. 1. Density at sea-surface pressure (σ_0), at 2000 decibars pressure (σ_2) and at 4000 decibars pressure (σ_4) as functions of salinity and potential temperature.