- Mar 27 Ch 4
- Mar 29 Ch 5 Q 7

- Apr 3 Ch 5 (Review)
- Apr 5 **Exam 2** (Ch 3, 4, and 5) (HW 7 originally due)

- Apr 10 Ch 5 HW 7 actually due here!!
- Apr 12 Ch 7 Q 8

- Apr 17 Ch 7
- Apr 19 Ch 7 Q 9, HW 8

- Apr 24 Ch 8
- Apr 26 Ch 8 Letter due

- May 1 Ch 8
- May 3 ? Q 10, HW 9

- May 8 ?
- May 10 **Exam 3** (Ch 5, 7, 8...?) HW 10

- May 15 Review and Wrap-up

- We’ve talked about what makes water **different** as a small molecule
- In particular, the effects of hydrogen bonding and polarity on determining what does and does not dissolve in water
- Let’s turn our attention to what contaminants are present in drinking water – how do we measure them, what do we do about it, etc.

In the U.S., the EPA has established two concentration limits for each contaminant:

The MCLG is the **maximum contaminant level *goal***, and reflects our understanding of the toxicity of the compound; this is the maximum safe concentration in drinking water

The MCL is the **maximum contaminant level**, and reflects the additional constraints of what can and cannot be accomplished using current technology

Table 5.11 MCLGs and MCLs (in ppm) for Selected Pollutants in Drinking Water

Pollutant	MCLG	MCL
Cadmium (Cd^{2+})	0.005	0.005
Chromium (Cr^{3+}, CrO_4^{2-})	0.1	0.1
Lead (Pb^{2+})	0	0.015
Mercury (Hg^{2+})	0.002	0.002
Nitrate (NO_3^-)	10	10
Benzene (C_6H_6)	0	0.005
Trihalomethanes ($CHCl_3$, etc.)	0	0.080

- Over time, more and more contaminants are identified and regulated
- Lower and lower MCLs are set as technologies improve, and as our understanding of the health effects improve
- Nonetheless, there are many things in your drinking water other than H_2O. How did they get there? And what efforts were made to keep them (and other things) out?

Treatment of Drinking Water

1) Water is passed through a mesh screen to remove large particles (sticks, fish, cans, bottles)
2) $Al_2(SO_4)_3$ and $Ca(OH)_2$ are added

   $Al_2(SO_4)_3(aq) + Ca(OH)_2(aq) \rightarrow 2\ Al(OH)_3(s) + 3\ CaSO_4(aq)$

   The $Al(OH)_3$ is sticky, and collects fine particles such as clays and dirt, before settling to the bottom
3) Further filtration is performed through gravel, and then sand

Treatment of Drinking Water

4) Then comes the most important, and most controversial part: disinfection

In the U.S., this is usually done with chlorine.

Can be introduced in several forms, but in solution, the active compound is HOCl, hypochlorous acid

HOCl is quite effective at killing bacteria and viruses. Before the introduction of chlorination, **cholera** was widespread and killed thousands (elsewhere, dysentery and giardia)

BUT

chlorinated water tastes different

chlorinated water may contain toxic levels of certain byproducts, particularly THMs (trihalomethanes)

Treatment of Drinking Water

Alternatives to chlorination:

Ozone: (widely used in Europe)

- More effective than chlorination at killing viruses
- More expensive – only viable on large scales
- Short-lived – it disinfects at the source, but doesn't protect the water once it leaves the plant
  - Often, the water leaving the plant is then chlorinated at low levels

Treatment of Drinking Water

Alternatives to chlorination:

UV irradiation

- Rapidly gaining popularity
- Like ozonation, it is more effective than chlorination
- Also cheaper and faster
- Still provides no protection to the water after it leaves the plant, so low-level chlorination is still required

- Nonetheless, there are many things in your drinking water other than H_2O. How did they get there? And what efforts were made to keep them (and other things) out?
- What can we be **certain** is in everyone's water, to some extent?
- **Ions.**

In particular, Ca^{2+} and Mg^{2+} ions

The concentration of these two ions determine how “hard” or “soft” your water is

Rather than specifying the aqueous concentration of the ions, we report “hardness” in mg/L – how much calcium carbonate **could** be formed from the ions present:

$$Ca^{2+}(aq) + CO_3^{2-}(aq) \rightarrow CaCO_3(s)$$

IF sufficient carbonate ions were present (an unlikely occurrence)

“Hard” water produces white deposits in hot water pipes, and soap rings in bathtubs

The ions react with soap to make a product which is NOT soluble in water

Precipitation reactions

Table 5.12 Classification of Water Hardness

Classification	mg/L (ppm)	grains/gal*
Soft	0–17.1	0–1
Slightly hard	17.1–60	1–3.5
Moderately hard	60–120	3.5–7.0
Hard	120–180	7.0–10.5
Very Hard	180 & over	10.5 & over

* One grain of hardness per gallon equals 17.1 mg/L (ppm). Many water-softening companies will test your water and report its hardness in grains/gallon.

Where do the “hardening” ions come from?
Limestone rock – a mixture of calcium carbonate and magnesium carbonate
Limestone is **partially** soluble in water, so flowing water carries ions into drinking supplies
Your book talks a lot more about this, and about ways to “soften” water – it’s a good read!
BUT – we’re going to move on to more toxic contaminants

Contaminants: Lead

Lead is a heavy metal

- Many heavy metals are toxic
- All of the metals near lead are toxic
- Lead, mercury and cadmium are all toxic, and all form 2+ ions which are soluble in water

Contaminants: Lead

Because lead is abundant, dense, and soft, it has been used in building materials since ancient times (The Fall of Rome?)

In the U.S., lead was primarily used in drinking water pipes, particularly in older cities.

No longer used! But there are lots of other ways to get lead into drinking water

Solder is often up to 75% lead – including the solder joining the copper pipes used today for drinking water and the solder which holds together many drinking fountains

Contaminants: Lead

Ingested lead causes severe and permanent neurological damage

In children, it leads to retardation and hyperactivity even at fairly low concentrations

In adults, it causes irritability, sleeplessness, irrational behavior and loss of appetite

Unlike many toxins, it is **cumulative** – that is, it is never eliminated from the body, but is stored in bones and in the brain

Contaminants: Lead

The EPA estimates that 1 in 6 American children has a blood lead level exceeding the health standards (from all sources)

The EPA has regulated lead in drinking water since 1970

The MCLG for lead is 0, which is extremely unusual for non-carcinogens

It is believed that less than 1% of U.S. public water systems, serving less than 3% of the population, exceed the MCL of 15 ppb

Contaminants: Lead

In the U.S., lead was primarily used in drinking water pipes, particularly in older cities.

It is believed that less than 1% of U.S. public water systems, serving less than 3% of the population, exceed the MCL of 15 ppb

But **which** 3% of the population **is** exposed to such concentrations?

Contaminants: Lead

As of 2001, the average lead concentration in drinking water at UMB was 28.4 ppb, above the MCL and well above the MCLG.

Remediation techniques were put into place, and the average concentration dropped 35% to 18.4 ppb – a dramatic improvement, but still above the legal limit

Water in Wheatley and Clark averages 11 ppb, below the MCL

Water in Healey Library averages more than 30 ppb

Contaminants: Lead

Your text recommends running the tap for a few seconds ("flushing") as a reliable way to reduce the Pb 2+ concentration

The Environmental Studies Group which conducted the UMB water survey found this to be quite **un**reliable – some fountains improved, but others did not

More details about the data and the results can be found on the poster in the display case in the Science building entryway

Contaminants: Arsenic

Arsenic is a metalloid, and forms both 3+ and 5+ ions which are soluble in water

Ingestion in high doses produces arsenic poisoning

Symptoms of arsenic poisoning start with mild headaches and can progress to lightheadedness and, if untreated, will result in death.

Symptoms include violent stomach pains in the region of the bowels; retching; vomiting;; thirst; hoarseness and difficulty of speech; convulsions and cramps; clammy sweats; delirium; death.

24 — Atomic number
Cr
52.00 — Atomic mass

1 1A	2 2A	3 3B	4 4B	5 5B	6 6B	7 7B	8 8B	9 8B	10 8B	11 1B	12 2B	13 3A	14 4A	15 5A	16 6A	17 7A	18 8A
1 **H** 1.008																	2 **He** 4.003
3 **Li** 6.941	4 **Be** 9.012											5 **B** 10.81	6 **C** 12.01	7 **N** 14.01	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.18
11 **Na** 22.99	12 **Mg** 24.31											13 **Al** 26.98	14 **Si** 28.09	15 **P** 30.97	16 **S** 32.07	17 **Cl** 35.45	18 **Ar** 39.95
19 **K** 39.10	20 **Ca** 40.08	21 **Sc** 44.96	22 **Ti** 47.88	23 **V** 50.94	24 **Cr** 52.00	25 **Mn** 54.94	26 **Fe** 55.85	27 **Co** 58.93	28 **Ni** 58.69	29 **Cu** 63.55	30 **Zn** 65.39	31 **Ga** 69.72	32 **Ge** 72.61	33 **As** 74.92	34 **Se** 78.96	35 **Br** 79.90	36 **Kr** 83.80
37 **Rb** 85.47	38 **Sr** 87.62	39 **Y** 88.91	40 **Zr** 91.22	41 **Nb** 92.91	42 **Mo** 95.94	43 **Tc** (98)	44 **Ru** 101.1	45 **Rh** 102.9	46 **Pd** 106.4	47 **Ag** 107.9	48 **Cd** 112.4	49 **In** 114.8	50 **Sn** 118.7	51 **Sb** 121.8	52 **Te** 127.6	53 **I** 126.9	54 **Xe** 131.3
55 **Cs** 132.9	56 **Ba** 137.3	57 **La** 138.9	72 **Hf** 178.5	73 **Ta** 180.9	74 **W** 183.9	75 **Re** 186.2	76 **Os** 190.2	77 **Ir** 192.2	78 **Pt** 195.1	79 **Au** 197.0	80 **Hg** 200.6	81 **Tl** 204.4	82 **Pb** 207.2	83 **Bi** 209.0	84 **Po** (210)	85 **At** (210)	86 **Rn** (222)
87 **Fr** (223)	88 **Ra** (226)	89 **Ac** (227)	104 **Rf** (261)	105 **Db** (262)	106 **Sg** (266)	107 **Bh** (264)	108 **Hs** (269)	109 **Mt** (268)	110 **Ds** (271)	111	112	113	114	115	(116)	(117)	(118)
				58 **Ce** 140.1	59 **Pr** 140.9	60 **Nd** 144.2	61 **Pm** (145)	62 **Sm** 150.4	63 **Eu** 152.0	64 **Gd** 157.3	65 **Tb** 158.9	66 **Dy** 162.5	67 **Ho** 164.9	68 **Er** 167.3	69 **Tm** 168.9	70 **Yb** 173.0	71 **Lu** 175.0
				90 **Th** 232.0	91 **Pa** 231.0	92 **U** 238.0	93 **Np** (237)	94 **Pu** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (252)	100 **Fm** (257)	101 **Md** (258)	102 **No** (259)	103 **Lr** (262)

Metals

Metalloids

Nonmetals

The 1–18 group designation has been recommended by the International Union of Pure and Applied Chemistry (IUPAC) but is not yet in wide use. In this text we use the standard U.S. notation for group numbers (1A–8A and 1B–8B). No names have been assigned for elements 111–115. Elements 116–118 have not yet been synthesized.

Contaminants: Arsenic

Arsenic poisoning has been particularly prevalent in Bangladesh and India: regular flooding produces contaminated surface waters, but the deep wells are contaminated with As

Chronic ingestion of much lower doses of As produces different symptoms, including jaundice, cirrhosis, anemia and various organ cancers

The World Health Organization recommends a limit of 10 ppb

Contaminants: Arsenic

In January 2001, the Clinton administration reduced the U.S. standard from 50 ppb to 10 ppb

The Bush administration revoked this change upon taking office, before the change could be enacted

Eventually, the EPA was swayed by WHO’s data, and set the limit at 10 ppb as of January 2006

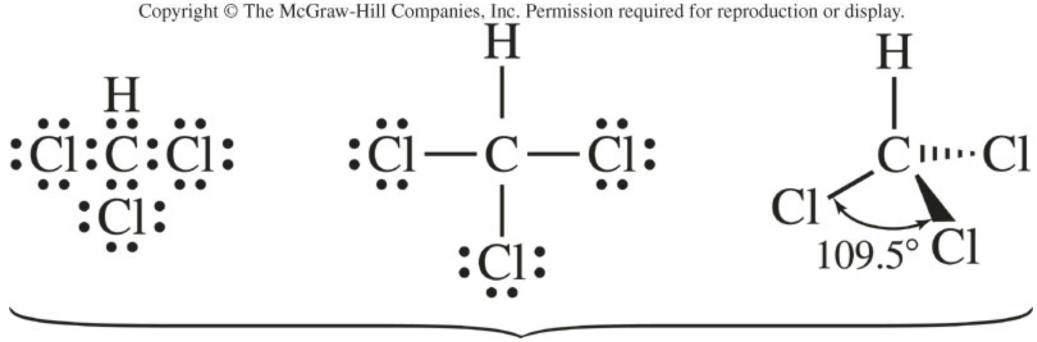
MANY U.S. drinking supplies do not meet this new standard

Contaminants: Trihalomethanes (THMs)

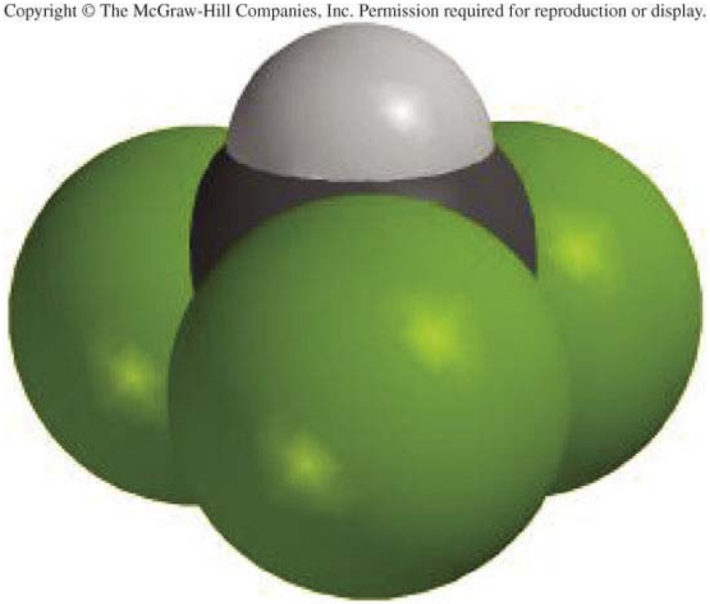
THMs are a class of compounds derived from methane (CH_4) in which 3 of the 4 H atoms have been replaced by halogens

Possibilities in drinking water include $CHCl_2Br$, $CHClBr_2$ and $CHBr_3$...

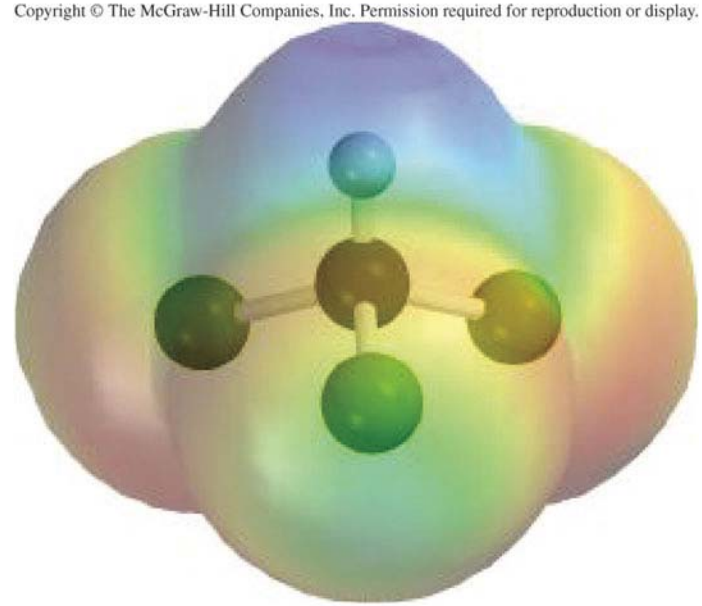
But the most prevalent is chloroform, $CHCl_3$.



(a)



(b)



(c)

Contaminants: Trihalomethanes (THMs)

THMs are formed from the reaction of HOCl with **humic acids**, which are formed from the breakdown of plant and animal matter in water

Humic acids are always present in surface waters...

... And so THMs are always present in chlorinated surface waters

THMs may be tasted in drinking waters, and can be smelled in heated water

Contaminants: Trihalomethanes (THMs)

- Chloroform is believed to cause liver cancer, and may also cause kidney and rectal cancers
- The current MCL is 80 ppb
- Most municipal supplies meet that standard – the national average is 54 ppb
- But this is a long way from the 0 ppb MCLG for all known carcinogens
- This has long been a contentious debate – the benefits of chlorination vs. the hazards of THMs

Contaminants: Others?

The EPA regulates hundreds of compounds in drinking water

Many of these are of historical interest, but pose no current threat in this country

But new technologies and new chemicals are always being invented, and so there will always be the need for new regulations as new toxins make their way into our water

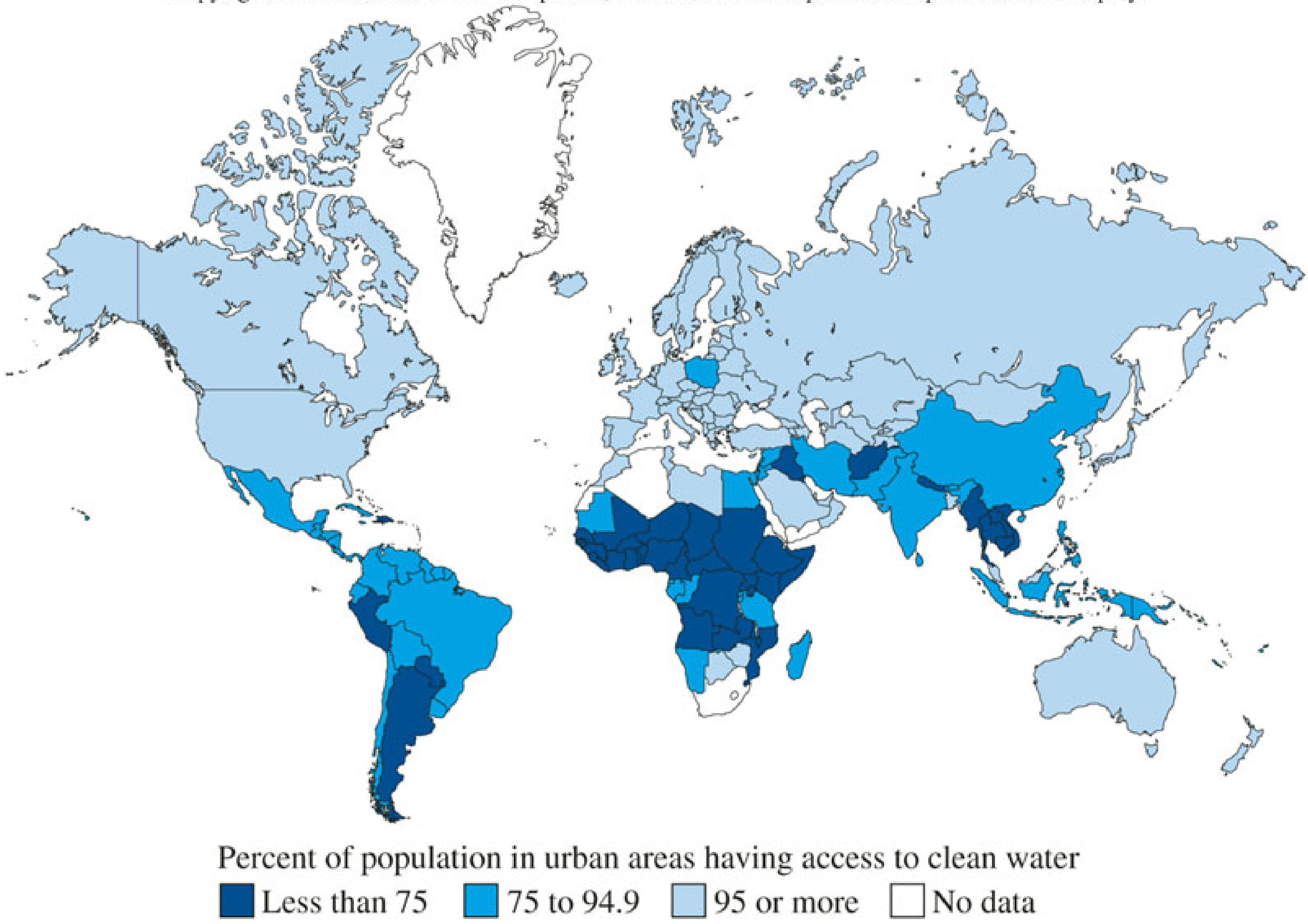
Safe Drinking Water

Looking beyond the U.S....

More than 1 billion people (1 in 6) lack access to safe drinking water

1.8 billion people do not have sanitation

One estimate is that is would cost 68 billion dollars over the next 10 years to address that deficiency


Percent of population in urban areas having access to clean water
Less than 75
75 to 94.9
95 or more
No data

Statistics

Total Point Available = 200 + 15 bonus

24 Exams Scored

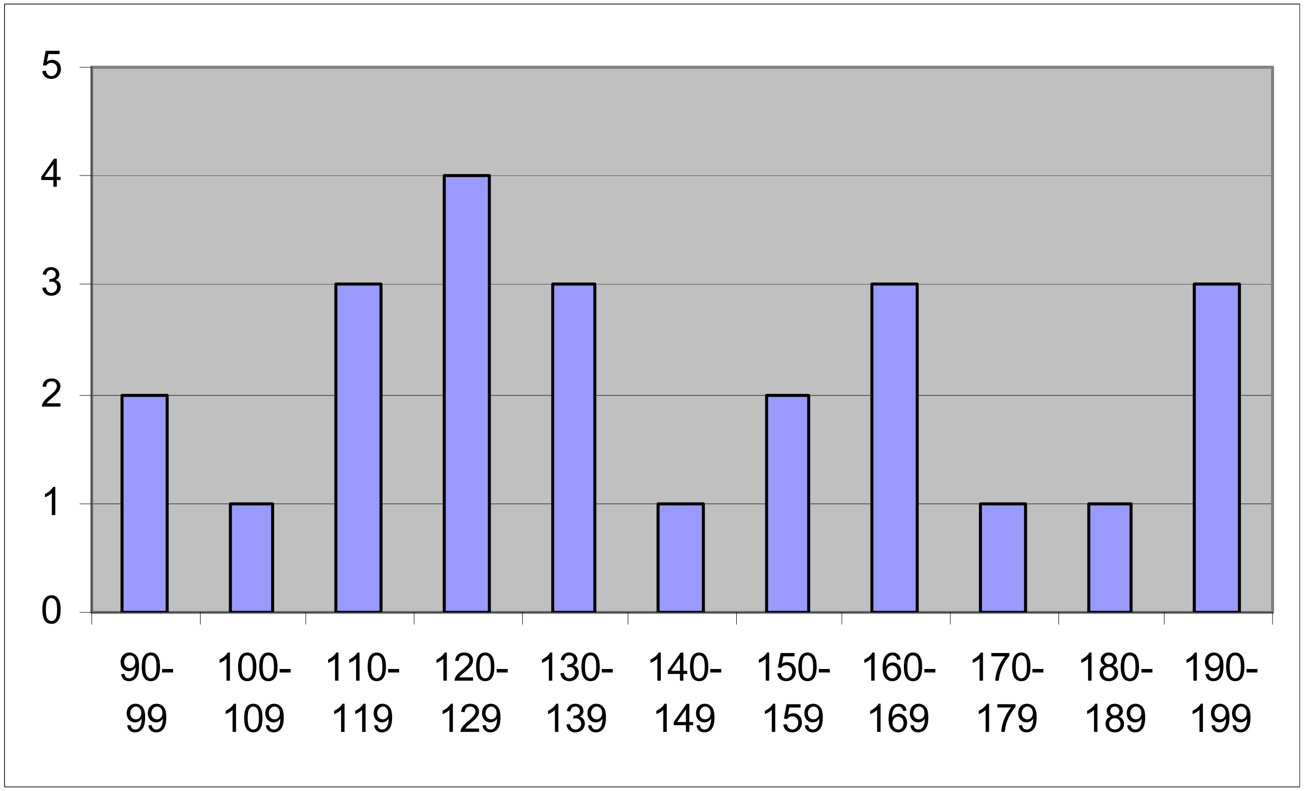
Average = 142

Median = 132

Standard Deviation = 31.7

High = 193

Low = 90



Safe Drinking Water

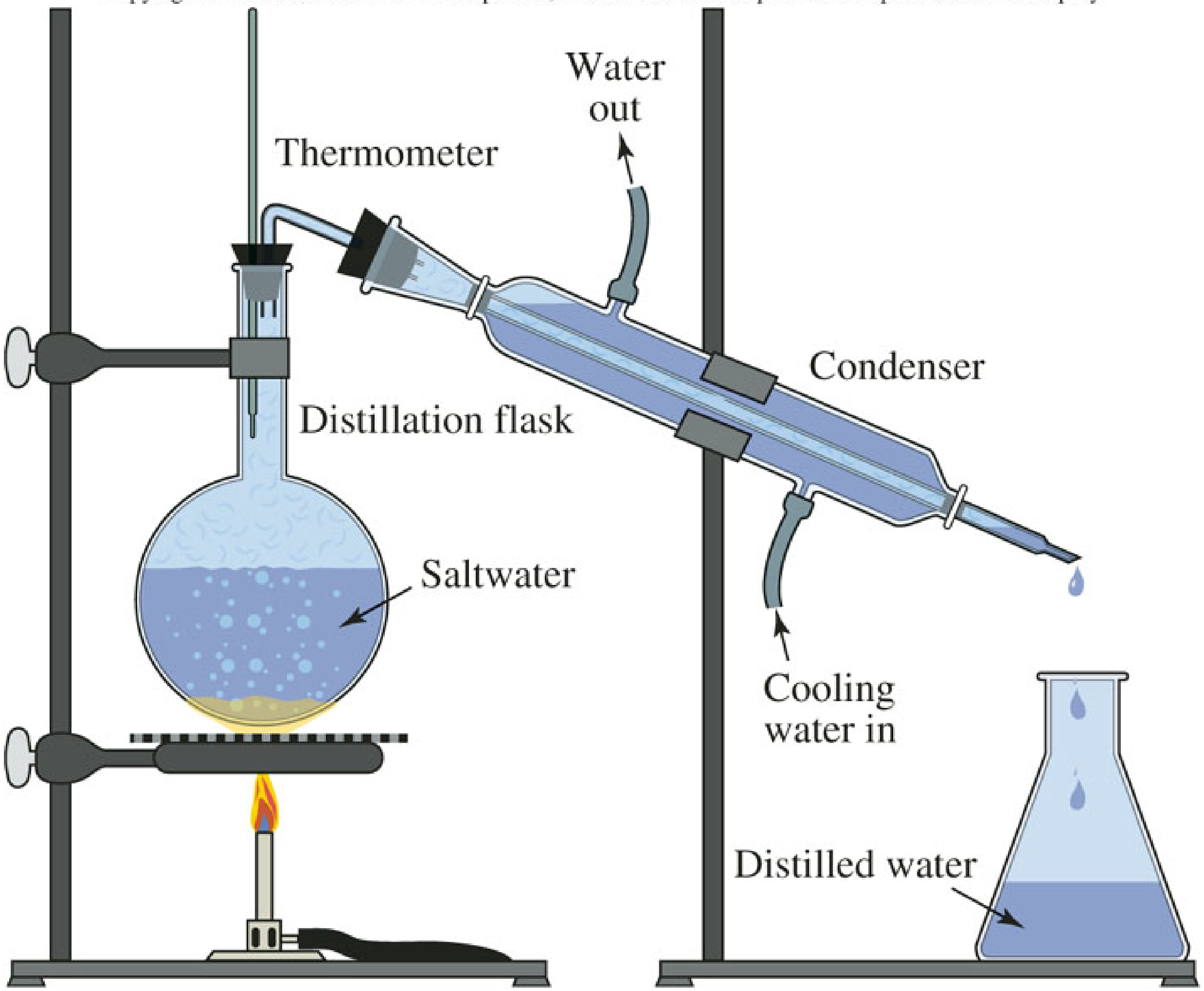
In addition to bacteria, viruses, metal ions and THMs, much of the world's water is too salty for consumption

Fortunately, there are ways to remove salt from sea water and make it palatable

Two primary techniques are **distillation** and **reverse osmosis**

Note: This slide and the three following were **not** covered in lecture, and will **not** be on the exam. However, they are important to understanding the global chemistry of drinking water.

Distillation



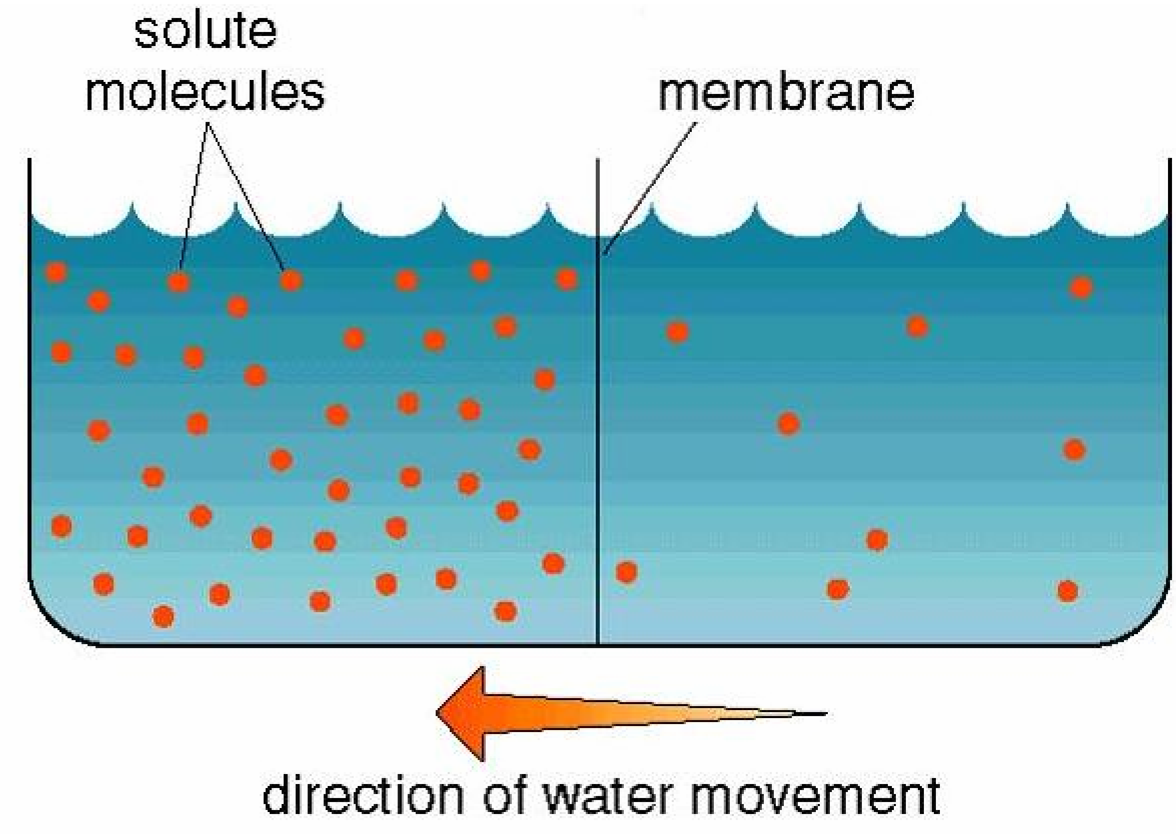
An ancient technique

Fairly simple apparatus

Can produce "distilled water" with **no** measurable contaminants

Requires LARGE amounts of energy, limiting it to countries with cheap and abundant energy

Osmosis



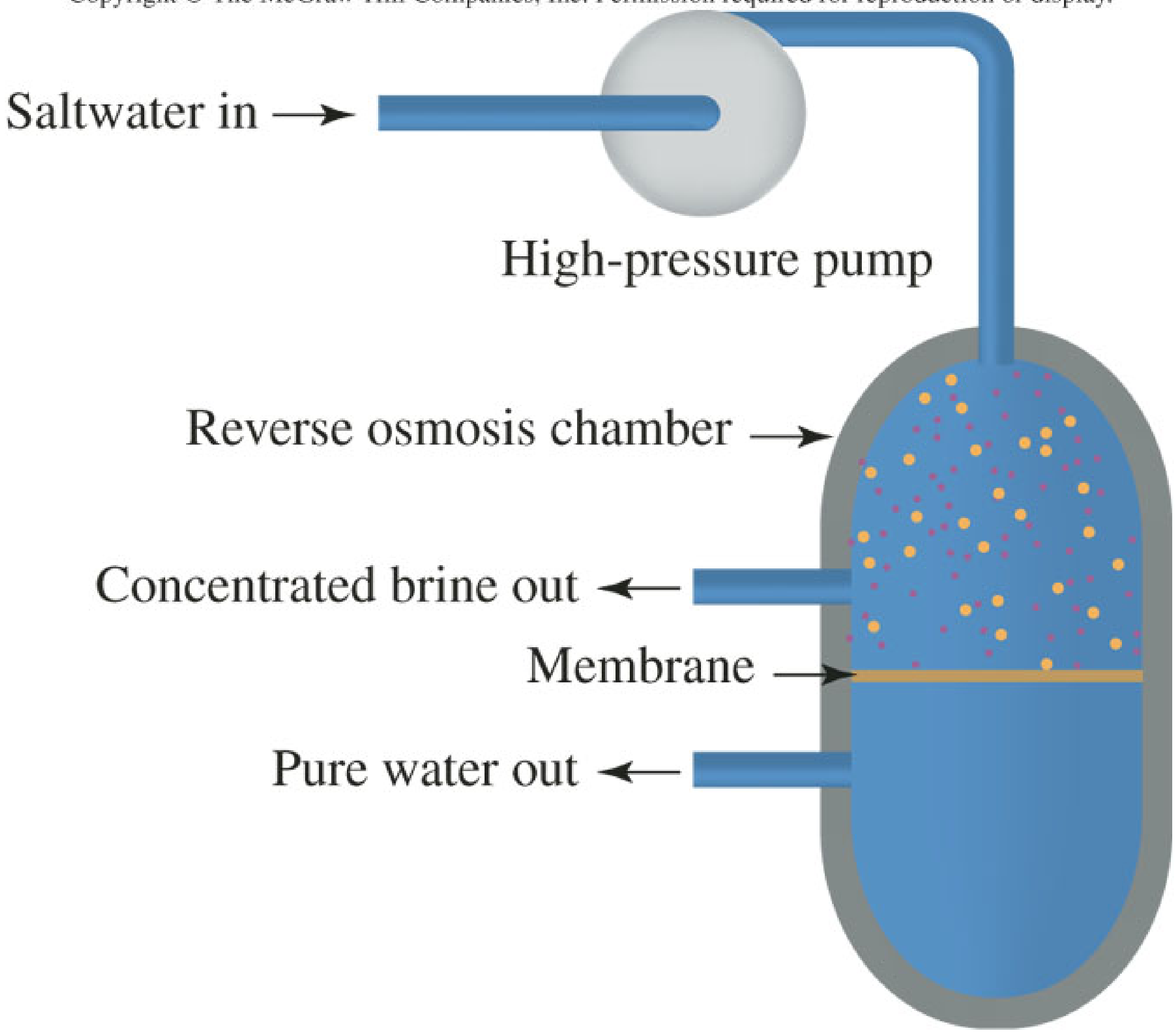
In biological organisms, osmosis is critical to regulating the concentration of ions (and other solutes) in cells

Water can pass through the membrane, but ions cannot

Water naturally moves to try and equalize the concentrations on either side of the membrane

This serves to **dilute** the more concentrated solution

Reverse Osmosis



Water can pass through the membrane, but ions cannot

If sufficient pressure is applied, water will pass through the membrane and leave solute ions behind

This technique is widely used in the Middle East

But it, too, is an expensive technique unavailable to developing nations