# ${\bf Solutions~to~Qing~Liu's} \\ {\bf \it Algebraic~Geometry~and~Arithmetic~Curves}$

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### Some topics in commutative algebra

#### roducts

	1. Tensor Prod
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Exercise 1.3.	
Exercise 1.4.	
Exercise 1.5.	
Exercise 1.6.	
Exercise 1.7.	
	2. Flatness
Exercise 2.1.	
Exercise 2.2.	
Exercise 2.3.	
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Exercise 2.5.	
Exercise 2.6.	
Exercise 2.7.	
Exercise 2.8.	
Exercise 2.9.	
Exercise 2.10.	
Exercise 2.11.	
Exercise 2.12.	
Exercise 2.13.	
Exercise 2.14.	

Exercise 2.15. Exercise 2.16.

- Exercise 2.17.
- Exercise 2.18.
- Exercise 2.19.
- Exercise 2.20.

#### 3. Formal completion

- Exercise 3.1.
- Exercise 3.2.
- Exercise 3.3.
- Exercise 3.4.
- Exercise 3.5.
- Exercise 3.6.
- Exercise 3.7.
- Exercise 3.8.
- Exercise 3.9.
- Exercise 3.10.
- Exercise 3.11.
- Exercise 3.12.
- Exercise 3.13.
- Exercise 3.14.
- Exercise 3.15.

### General properties of schemes

	1. Spectrum of a ring
Exercise 1.1.	
Exercise 1.2.	
Exercise 1.3.	
Exercise 1.4.	
Exercise 1.5.	
Exercise 1.6.	
Exercise 1.7.	
Exercise 1.8.	
Exercise 1.9.	
	2. Ringed topological spaces
Exercise 2.1.	
Exercise 2.2.	
Exercise 2.3.	
Exercise 2.4.	
Exercise 2.5.	
Exercise 2.6.	
Exercise 2.7.	
Exercise 2.8.	
Exercise 2.9.	
Exercise 2.10.	
Exercise 2.11.	
Exercise 2.12.	
Exercise 2.13.	
Exercise 2.14	

#### 3. Schemes

- Exercise 3.1.
- Exercise 3.2.
- Exercise 3.3.
- Exercise 3.4.
- Exercise 3.5.
- Exercise 3.6.
- Exercise 3.7.
- Exercise 3.8.
- Exercise 3.9.
- Exercise 3.10.
- Exercise 3.11.
- Exercise 3.12.
- Exercise 3.13.
- Exercise 3.14.
- Exercise 3.15.
- Exercise 3.16.
- Exercise 3.17.
- Exercise 3.18.
- Exercise 3.19.
- Exercise 3.20.
- Exercise 3.21.
- Exercise 3.22.
- Exercise 3.23.

#### 4. Reduced schemes and integral schemes

- Exercise 4.1.
- Exercise 4.2.
- Exercise 4.3.
- Exercise 4.4.
- Exercise 4.5.
- Exercise 4.6.

5. DIMENSION 9

5. Dimension

Exercise 4.7.
Exercise 4.8.
Exercise 4.9.
Exercise 4.10.
Exercise 4.11.
Exercise 4.12.
Exercise 5.1.
Exercise 5.2.
Exercise 5.3.
Exercise 5.4.
Exercise 5.5.
Exercise 5.6.
Exercise 5.7.
Exercise 5.8.
Exercise 5.9.

Exercise 5.10.
Exercise 5.11.
Exercise 5.12.
Exercise 5.13.
Exercise 5.14.
Exercise 5.15.

### Morphisms and base change

#### 1. The technique of base change

Exercise 1.1. Exercise 1.2. Exercise 1.3. Exercise 1.4. Exercise 1.5. Exercise 1.6. Exercise 1.7. Exercise 1.8. Exercise 1.9. Exercise 1.10. Exercise 1.11. 2. Applications to algebraic varieties Exercise 2.1. Exercise 2.2. Exercise 2.3. Exercise 2.4. Exercise 2.5. Exercise 2.6. Exercise 2.7. Exercise 2.8. Exercise 2.9. Exercise 2.10. Exercise 2.11. Exercise 2.12.

- Exercise 2.13. Exercise 2.14. Exercise 2.15.
- Exercise 2.16. Exercise 2.17.
- Exercise 2.18.
- Exercise 2.19.
- Exercise 2.20.
- Exercise 2.21.

#### ${\bf 3. \ \ Some \ global \ properties \ of \ morphisms}$

- Exercise 3.1.
- Exercise 3.2.
- Exercise 3.3.
- Exercise 3.4.
- Exercise 3.5.
- Exercise 3.6.
- Exercise 3.7.
- Exercise 3.8.
- Exercise 3.9.
- Exercise 3.10.
- Exercise 3.11.
- Exercise 3.12.
- Exercise 3.13.
- Exercise 3.14.
- Exercise 3.15.
- Exercise 3.16.
- Exercise 3.17.
- Exercise 3.18.
- Exercise 3.19.
- Exercise 3.20.
- Exercise 3.21.

- Exercise 3.22.
- Exercise 3.23.
- Exercise 3.24.
- Exercise 3.25.
- Exercise 3.26.
- Exercise 3.27.

### Some local properties

#### 1. Normal schemes

Exercise 1.1.	
Exercise 1.2.	
Exercise 1.3.	
Exercise 1.4.	
Exercise 1.5.	
Exercise 1.6.	
Exercise 1.7.	
Exercise 1.8.	
Exercise 1.9.	
Exercise 1.10.	
Exercise 1.11.	
Exercise 1.12.	
Exercise 1.13.	
Exercise 1.14.	
Exercise 1.15.	
Exercise 1.16.	
Exercise 1.17.	
Exercise 1.18.	
Exercise 1.19.	
	2. Regular schemes
Exercise 2.1.	
Exercise 2.2.	
Exercise 2.3.	

Exercise 2.4.

3. Flat morphisms and smooth morphisms

Exercise 2.5. Exercise 2.6. Exercise 2.7. Exercise 2.8. Exercise 2.9. Exercise 2.10. Exercise 2.11. Exercise 2.12. Exercise 2.13. Exercise 3.1. Exercise 3.2. Exercise 3.3. Exercise 3.4. Exercise 3.5. Exercise 3.6. Exercise 3.7. Exercise 3.8. Exercise 3.9. Exercise 3.10. Exercise 3.11. Exercise 3.12. Exercise 3.13. Exercise 3.14. Exercise 3.15. Exercise 3.16. Exercise 3.17. Exercise 3.18.

Exercise 3.20. Exercise 3.21.

Exercise	3.22.
Exercise	3.23.
Exercise	3.24.

Exercise 3.25.

Exercise 3.26.

#### 4. Zariski's 'Main Theorem' and applications

Exercise 4.1.

Exercise 4.2.

Exercise 4.3.

Exercise 4.4.

Exercise 4.5.

Exercise 4.6.

### Coherent sheaves and Čech cohomology

#### 1. Coherent sheaves on a scheme

- Exercise 1.1.
- Exercise 1.2.
- Exercise 1.3.
- Exercise 1.4.
- Exercise 1.5.
- Exercise 1.6.
- Exercise 1.7.
- Exercise 1.8.
- Exercise 1.9.
- Exercise 1.10.
- Exercise 1.11.
- Exercise 1.12.
- Exercise 1.13.
- Exercise 1.14.
- Exercise 1.15.
- Exercise 1.16.
- Exercise 1.17.
- Exercise 1.18.
- Exercise 1.19.
- Exercise 1.20.
- Exercise 1.21.
- Exercise 1.22.
- Exercise 1.23.
- Exercise 1.24.

Exercise 1.26.

Exercise 1.27.

Exercise 1.28.

Exercise 1.29.

Exercise 1.30.

Exercise 1.31.

Exercise 1.32.

Exercise 1.33.

#### 2. Čech cohomology

#### Exercise 2.1.

Exercise 2.2.

Exercise 2.3.

Exercise 2.4.

Exercise 2.5.

Exercise 2.6.

Exercise 2.7.

Exercise 2.8.

Exercise 2.9.

Exercise 2.10.

Exercise 2.11.

Exercise 2.12.

Exercise 2.13.

Exercise 2.14.

Exercise 2.15.

Exercise 2.16.

Exercise 2.17.

#### 3. Cohomology of projective schemes

- Exercise 3.1.
- Exercise 3.2.
- Exercise 3.3.
- Exercise 3.4.
- Exercise 3.5.
- Exercise 3.6.
- Exercise 3.7.
- Exercise 3.8.
- Exercise 3.9.
- Exercise 3.10.
- Exercise 3.11.
- Exercise 3.12.
- Exercise 3.13.
- Exercise 3.14.
- Exercise 3.15.

### Sheaves of differentials

#### 1. Kähler differentials

Exercise 1.1.	
Exercise 1.2.	
Exercise 1.3.	
Exercise 1.4.	
Exercise 1.5.	
Exercise 1.6.	
Exercise 1.7.	
Exercise 1.8.	
Exercise 1.9.	
	2. Differential study of smooth morphisms
Exercise 2.1.	
Exercise 2.2.	
Exercise 2.3.	
Exercise 2.4.	
Exercise 2.5.	
Exercise 2.6.	
Exercise 2.7.	
Exercise 2.8.	
Exercise 2.9.	
Exercise 2.10.	
Exercise 2.11	

#### ${\bf 3. \ Local \ complete \ intersection}$

- Exercise 3.1.
- Exercise 3.2.
- Exercise 3.3.
- Exercise 3.4.
- Exercise 3.5.
- Exercise 3.6.
- Exercise 3.7.
- Exercise 3.8.

#### 4. Duality theory

- Exercise 4.1.
- Exercise 4.2.
- Exercise 4.3.
- Exercise 4.4.
- Exercise 4.5.
- Exercise 4.6.
- Exercise 4.7.
- Exercise 4.8.
- Exercise 4.9.
- Exercise 4.10.
- Exercise 4.11.

## Divisors and applications to curves

#### 1. Cartier divisors

Exercise 1.1.	
Exercise 1.2.	
Exercise 1.3.	
Exercise 1.4.	
Exercise 1.5.	
Exercise 1.6.	
Exercise 1.7.	
Exercise 1.8.	
Exercise 1.9.	
Exercise 1.10.	
Exercise 1.11.	
Exercise 1.12.	
Exercise 1.13.	
	2. Weil divisors
Exercise 2.1.	
Exercise 2.2.	
Exercise 2.3.	
Exercise 2.4.	
Exercise 2.5.	
Exercise 2.6.	
	3. Riemann-Roch theorem
Exercise 3.1.	
Exercise 3.2.	
Exercise 3.3.	
Exercise 3.4.	
Exercise 3.5.	

#### 4. Algebraic curves

Exercise 4.1.
Exercise 4.2.
Exercise 4.3.
Exercise 4.4.
Exercise 4.5.
Exercise 4.6.
Exercise 4.7.
Exercise 4.8.
Exercise 4.10.
Exercise 4.11.
Exercise 4.11.
Exercise 4.12.
Exercise 4.13.
Exercise 4.14.
Exercise 4.15.

- 5. Singular curves, structure of  $Pic^0(X)$
- Exercise 5.1.
  Exercise 5.2.
  Exercise 5.3.
  Exercise 5.4.
  Exercise 5.5.
  Exercise 5.6.
  Exercise 5.7.
  Exercise 5.8.
  Exercise 5.9.

Exercise 5.10.

Exercise 4.16. Exercise 4.17. Exercise 4.18.

### Birational geometry of surfaces

#### 1. Blowing-ups

Exercise 1.2.
Exercise 1.3.
Exercise 1.4.

Exercise 1.1.

- Exercise 1.5. Exercise 1.6.
- Exercise 1.7.
- Exercise 1.8.

#### 2. Excellent schemes

- Exercise 2.1.
- Exercise 2.2.
- Exercise 2.3.
- Exercise 2.4.
- Exercise 2.5.
- Exercise 2.6.
- Exercise 2.7.
- Exercise 2.8.
- Exercise 2.9.
- Exercise 2.10.
- Exercise 2.11.
- Exercise 2.12.
- Exercise 2.13. Exercise 2.14.
- Exercise 2.15.
- Exercise 2.16.
- Exercise 2.17.
- Exercise 2.18.

#### 3. Fibered surfaces

- Exercise 3.1.
- Exercise 3.2.
- Exercise 3.3.
- Exercise 3.4.
- Exercise 3.5.
- Exercise 3.6.
- Exercise 3.7.
- Exercise 3.8.
- Exercise 3.9.
- Exercise 3.10.
- Exercise 3.11.
- Exercise 3.12.
- Exercise 3.13.
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- Exercise 3.16.
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- Exercise 3.19.
- Exercise 3.20.
- Exercise 3.21.
- Exercise 3.22.
- Exercise 3.23.
- Exercise 3.24.
- Exercise 3.25.
- Exercise 3.26.
- Exercise 3.27.
- Exercise 3.28.

### Regular surfaces

#### 1. Intersection theory on a regular surface

Exercise 1.1. Exercise 1.2. Exercise 1.3. Exercise 1.4. Exercise 1.5. Exercise 1.6. Exercise 1.7. Exercise 1.8. Exercise 1.9. Exercise 1.10. Exercise 1.11. Exercise 1.12. Exercise 1.13. Exercise 1.14. Exercise 1.15. 2. Intersection and morphisms Exercise 2.1. Exercise 2.2. Exercise 2.3. Exercise 2.4. Exercise 2.5. Exercise 2.6. Exercise 2.7.

Exercise 2.8.

Exercise 4.15. Exercise 4.16.

#### $CHAPTER \ 10$

## Reduction of algebraic curves

#### 1. Models and reductions

Exercise	1.1.	
Exercise	1.2.	
Exercise	1.3.	
Exercise	1.4.	
Exercise	1.5.	
Exercise	1.6.	
Exercise	1.7.	
Exercise	1.8.	
Exercise	1.9.	
Exercise	1.10.	
Exercise	1.11.	
Exercise	1.12.	
Exercise	1.13.	
Exercise	1.14.	
Exercise	1.15.	
Exercise	1.16.	
Exercise	1.17.	
Exercise	1.18.	
Exercise	1.19.	
		2. Reduction of elliptic curves
Exercise	2.1.	
Exercise	2.2.	
Exercise	2.3.	
Exercise	2.4.	

Exercise 2.5.	
Exercise 2.6.	
Exercise 2.7.	
Exercise 2.8.	
Exercise 2.9.	
	3. Stable reduction of algebraic curves
Exercise 3.1.	
Exercise 3.2.	
Exercise 3.3.	
Exercise 3.4.	
Exercise 3.5.	
Exercise 3.6.	
Exercise 3.7.	
Exercise 3.8.	
Exercise 3.9.	
Exercise 3.10.	
Exercise 3.11.	
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Exercise 3.14.	
Exercise 3.15.	
Exercise 3.16.	
Exercise 3.17.	
Exercise 3.18.	
Exercise 3.19.	
Exercise 3.20.	
	4. Deligne-Mumford theorem
Exercise 4.1.	

Exercise 4.2. Exercise 4.3. Exercise 4.4.

- Exercise 4.5.
- Exercise 4.6.
- Exercise 4.7.
- Exercise 4.8.
- Exercise 4.9.